ASSESSMENT OF SUGAR MAPLE AND YELLOW BIRCH FOLIAGE AND SOIL CHEMISTRY AT THE ONTARIO HARDWOOD DECLINE SURVEY PLOTS

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EXECUTIVE SUMMARY

The present study was initiated by the Ontario Ministry of the Environment, as part of the Terrestrial Effects program of the Acidic Precipitation in Ontario Study (APIOS). Since most studies of foliage and soil chemistry conducted in Ontario are localized, there is little data regarding baseline levels of these attributes on a broad regional scale. The main objective of this study was to collect foliage and soil samples for analyses for two tree species, yellow birch (Betula alleghaniensis Britton) and sugar maple (Acer saccharum Marsh) from their natural ranges, in conjunction with plots established for the Ontario Hardwood Decline Survey. The information collected would be used to estimate variation in soil and foliage chemistry across Ontario, for designing future sampling protocols, and would provide a baseline of current conditions against which future studies could be compared.

This report includes evaluations of the variability of sugar maple and yellow birch foliage and associated soil chemistry; comparisons of the results of this study with the scientific literature; estimates of sample size requirements for various foliage and soil elements, to assist the design of future sampling protocols; summaries of regional variations in foliage and soil attributes; and correlations between foliage and soil chemistry attributes, decline index, tree heights and diameters, and other site features.

In general, the ranges of soil and foliage chemistry described herein correspond well with the ranges reported in similar studies in Ontario and in other jurisdictions. Neither the soils or foliage sampled shows signs of marked nutrient imbalances or deficiencies; despite the fact that many of the granitic till soils on the Canadian Shield were quite acidic.

Further analyses showed that the levels of certain soil and foliage elements are significantly correlated, while other elements in the foliage appear to be unrelated to soil levels. For example, nitrogen levels in the foliage of sugar maple remain relatively constant throughout the study plots despite differences in soil levels. Correlations between soils and foliage element levels showed that soil pH is the soil attribute most consistently correlated with the foliage element levels, along with soil Al, which is highly correlated with pH. In general, low pH soils tend to be associated with higher levels of soil Al, Fe, Ni and Pb; and lower levels of Ca, Mg, Cu and Zn, and lower CEC. The foliage of trees of both species on soils with lower pH values tended to have lower levels of Ca and Mg, and higher levels of Mn, Cu and Zn. Yellow birch foliage also tended to have lower N levels on low pH soils.

Increasing decline index for both tree species was correlated with lower soil pH values and higher foliar Mn levels. For yellow

birch, higher decline indices tended to be associated with lower foliar K, Ca, S, Al and Cl levels, and higher foliar Cd and Ni levels. For sugar maple, higher decline indices tended to be associated with higher foliar Pb levels.

These results are mainly intended to provide a baseline against which future studies in Ontario and elsewhere can be compared. Cause-and-effect relationships between soil features and foliage chemistry, and between atmospheric deposition levels and soil and foliage chemistry, cannot be established from the results of this study.

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1.0 INTRODUCTION

The present study was initiated by the Ontario Ministry of the Environment, as part of the Terrestrial Effects program of the Acidic Precipitation in Ontario Study (APIOS). Since most studies of foliage and soil chemistry conducted in Ontario are localized, there is little data regarding baseline levels of these attributes on a broad regional scale. The main objective of this study was to collect foliage and soil samples for analyses for two tree species, yellow birch (Betula alleghaniensis Britton) and sugar maple (Acer saccharum Marsh) from their natural ranges, in conjunction with plots established for the Ontario Hardwood Decline Survey (McIlveen et al. 1988).

The information collected would be used to estimate variation in soil and foliage chemistry across Ontario, for designing future sampling protocols, and would provide a baseline of current conditions against which future studies could be compared. Further objectives included determining if relationships exist between soil and foliar chemistry, and if decline state of sugar maple or yellow birch is related to either of these.

Ecological Services for Planning Limited was retained to implement the sampling program, and to synthesize and analyse the resulting information.

2.0 TECHNICAL PROGRAM

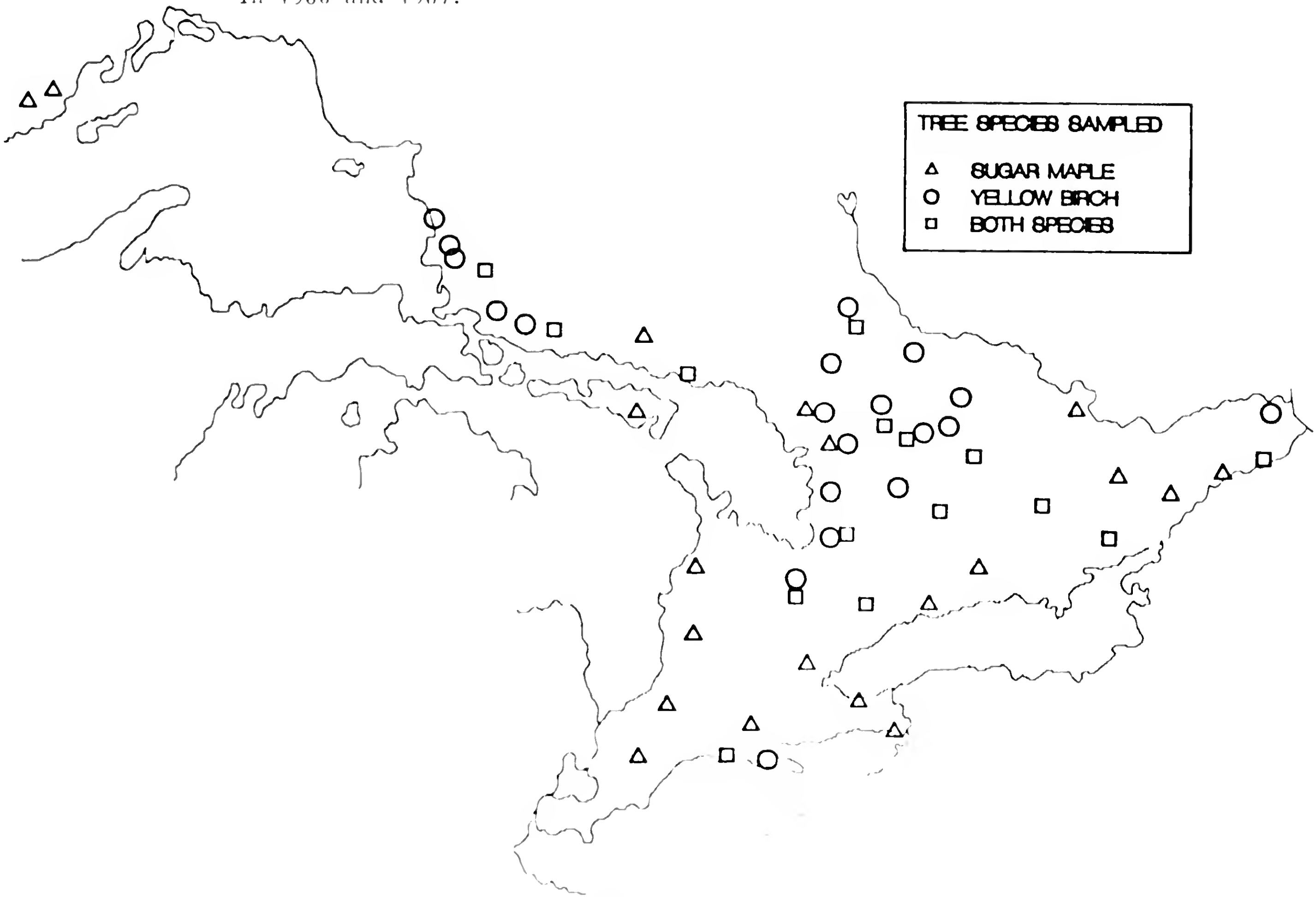
2.1 Overview and Objectives

During the summer of 1986, samples of soil and sugar maple foliage were collected from thirty-five plots distributed throughout the natural range of sugar maple in Ontario, including the Great Lakes-St. Lawrence and the Deciduous Forest Regions in Ontario as defined by Rowe (1972). Ontario Ministry of Natural Resources Administrative Districts were used as the basis for sample distribution. At least one study plot was selected for sugar maple sampling from each District.

In 1987, additional soil and yellow birch foliage samples were collected from thirty-five hardwood decline plots distributed as evenly as possible throughout the survey area (Figure 1). Since yellow birch is less common in southern Ontario than in the north, the distribution of sampled plots is skewed to northern Ontario. Where possible, yellow birch samples were obtained from the same plots from which sugar maple foliage and soil samples had been previously collected. This minimized the amount of soil sampling required and allowed direct comparison of the results from these plots. Geographic data regarding the locations of the foliage and soil sampling sites are summarized in Appendix 1.

The main purposes of the sampling program were to obtain baseline data to examine variability in foliage chemistry in Ontario for

FIGURE 1: General distibutions of the Hardwood Decline Survey plots sampled for sugar maple and yellow birch foliage and soils in Ontario, in 1986 and 1987.



sugar maple and yellow birch, and to examine relationships between soil and foliage chemistry, both between and within plots.

With a fixed sample, the precision of estimates of mean soil and foliar chemistry will depend on the variability associated with each element. This will dictate the ability to conduct further analyses on the data. Specific objectives of the data analyses included:

i) determine the natural variability in soil and foliar element concentrations within the Study area for estimating future sampling requirements;

ii) determine if any relationships exist between element levels in the foliage and the soil on each plot;

iii) determine if a relationship exists between soil and foliar chemistry and the observed decline indices for each plot; and

iv) identify and describe regional variations in soil and foliar chemistry.

2.2 Sampling Considerations

There are four main sources of variation in sugar maple and yellow birch foliar chemistry that are of concern in designing sampling methods:

i) Temporal variation and time of sampling;

ii) Sample position within the crown;

iii) Maturity of the foliage; and

iv) Natural variability of foliar chemistry.

These sources of variation make it difficult to determine the number of trees necessary to obtain a foliar chemical sample mean within acceptable confidence limits.

The concentration of foliar inorganic elements in sugar maple and yellow birch remains relatively constant from late June to late August (Leaf 1973; Hoyle 1965). This period represents the ideal sampling "window" for these species. There is some evidence of calcium (Ca) accumulation in foliage over the course of the growing season, so increased Ca levels may be observed if sampling is conducted late in the window (Morrison 1985). In Northern Ontario, maturity of the leaves occurs later, and some fall colouration may begin near the end of August. Hence, the sampling window in Northern Ontario is narrower, ideally from early to mid-August (Morrison 1985).

Morrison (1985) studied the effect of crown position on foliar concentrations of 11 elements in sugar maple and yellow birch on a till soil, at the Turkey Lakes watershed near Sault Ste. Marie, Ontario. He concluded that samples obtained from the lower and middle portions of the crown yield similar results, and are less variable than samples from the upper crown. At middle and lower crown positions, fewer samples are required to obtain accurate estimates of the concentrations of elements in the leaves. Morrison suggests that a minimum of ten sugar maple trees should be sampled to obtain a standard error of approximately 10% about the mean for macronutrient elements (N, P, K, Ca, Mg, and S), and up to thirty trees are required for more variable elements such as Mn.

Variability in foliage chemistry in other parts of Ontario may differ from the results indicated by Morrison's study. Furthermore, for a large scale sampling program, cost and time constraints usually dictate the number of samples that can practicably be obtained. The desired level of precision can be adjusted to meet the objectives of the study (for example, from +/-10% to +/-20%).

For the purposes of this study, three branches were collected from different locations within the lower and middle portions of the crown from each tree. These three samples were then bulked to form a single sample. Five individual sugar maple or yellow birch trees

were sampled in this manner at each plot. If between-tree variability is consistent with Morrison's work, this can be expected to yield estimates of mean foliar macronutrient levels for each plot to within 10 to 20 percent, at the 95% confidence level.

2.3 Sugar Maple Foliage and Associated Soil Sampling

Sugar maple foliage and soil samples were collected from thirty-five of the Hardwood Decline study plots during the 1986 field season (Appendix 1). At least one plot was selected from each MNR District to obtain the best possible geographic distribution over the Study area. Sites were also selected on the basis of obtaining a range of soil conditions for sampling purposes (Appendix 2).

Soil samples were obtained from soil pits located near the centre of each of the thirty-five plots, for each of the 'A', 'B', and 'C' mineral soil horizons. Some of the shallow mineral soils over bedrock or cobbly till had only two horizons. Samples were placed in plastic lined paper bags, sealed, and appropriately labelled.

Samples of foliage were collected from five trees located just outside the perimeter of each plot, to avoid disturbing the trees marked for reassessment within the permanent assessment plots. Azimuths and distances to the trees from the plot's centre point were recorded, in addition to the diameter at breast height (DBH) and height to the base of the living crown for each tree.

Foliar samples were collected with pruning poles from the selected trees. A plastic sheet was placed at the base of each tree to be sampled, to prevent contamination of the samples as they fell to the ground. Leaves were stripped from the branches and placed in

plastic bags, one for each of the three subsamples, wearing rubber gloves to prevent contamination. Leaves that were necrotic, damaged by insects, or had fungal structures or other obvious defects were discarded to minimize potential variability due to these uncontrolled variables.

The plastic bags were appropriately labelled and stored on ice in coolers during transport. The samples were frozen within a day and were stored frozen until processed.

The foliar samples were dried at 80°C in a forced draft oven and ground to less than 1 mm in a Wiley Mill. Soil samples were air dried, disaggregated with a mortar and pestle, and passed through a 2 mm sieve. A subsample of the less than 2 mm fraction was then ground in an automated grinder to completely pass through a 150 micrometre sieve. Equipment was cleaned carefully between each sample to avoid contamination. Samples were bottled and labelled, then submitted to the Ministry of the Environment, with the appropriate documentation for chemical analyses (Appendix 3).

2.4 Yellow Birch Foliage and Associated Soil Sampling

Sampling of yellow birch foliage and associated soil was conducted on thirty-five plots during the summer of 1987. Five trees were sampled in each plot using the same methods described for sugar maple. Trees were selected either within the plot boundaries, or immediately adjacent to the plot, depending on the amount of yellow birch in the stand.

Each yellow birch tree sampled was numbered from 'S1' to 'S5' using blue tree marking paint. The location of each tree from the center of the plot was also recorded, and each sampled yellow birch tree was assessed separately for decline attributes, as described in McIlveen et al. (1988), and for total height and DBH.

Three soil cores from the 0 to 30 cm depth were collected using a dutch soil auger, and bulked into a single sample of the mineral soil (i.e. excluding the organic LFH layers) from within one metre of the base of each yellow birch tree sampled. This sampling depth was selected since the majority of tree feeder roots would be expected to occur within this zone (Gale and Grigal 1987). The soil cores usually included the 'A' and upper 'B' soil horizons within the major rooting zone of the tree. A total of 175 yellow birch foliage samples and 175 soil core samples were collected (35 sites x 5 trees).

Soil pits were also dug near the center of each plot, approximately

one cubic metre in size. From each pit, duplicate samples were taken of the 'A', 'B' and 'C' mineral soil horizons from opposite sides of the pit. Fifteen of the plots on which the yellow birch were sampled had been sampled in 1986 for sugar maple foliage and soil, hence, the soil pits were not resampled on these plots, although soil core samples were taken around all sampled birch trees (Table 1).

A total of 110 soil samples were collected from the soil pits on the 20 remaining sites. Six of the plots were located on shallow soils over bedrock, and for these plots, only two soil horizons were present (typically the Ae and Bm horizons). One plot was located on a deep mineral soil with a contrasting mode of deposition (sandy glaciofluvial material over coarse till). On this plot, four soil horizons were sampled, the A, B, C1 and C2 horizons.

Soil samples were placed in appropriately labelled plastic-lined soil sample bags and shipped to the laboratory for drying and processing.

Foliage and soil samples were prepared for laboratory analyses using the same methods described for sugar maple. The dried and ground samples were bottled and labelled, and then submitted to the

TABLE 1: Summary of foliage and soil samples collected for the study.

TREE SPECIES SAMPLED	NUMBER OF PLOTS SAMPLED	FOLIAGE SAMPLES	SOIL CORES	SOIL PITS	DUPLICATE SAMPLES FROM PITS
Sugar Maple Only	20	100	none	20 pits; all horizons	no
Yellow Birch Only	20	100	100	20 pits; all horizons	yes
Both Species	15	75 Mh 75 By	none 75	15 pits; all horizons	no
Total Plots/Samples Collected:	55	350	175	201	

Ministry of the Environment with the appropriate documentation for chemical analyses. Chemical analyses were completed by MOE for both the foliar and the soil samples as listed in Appendix 3. The laboratory procedures used for the various chemical analyses are documented in "Procedures Manual, Terrestrial Effects, Acidic Precipitation in Ontario Study" (Technical Subcommitee, Terrestrial Effects Working Group 1986).

3.0 DATA HANDLING AND ANALYSES

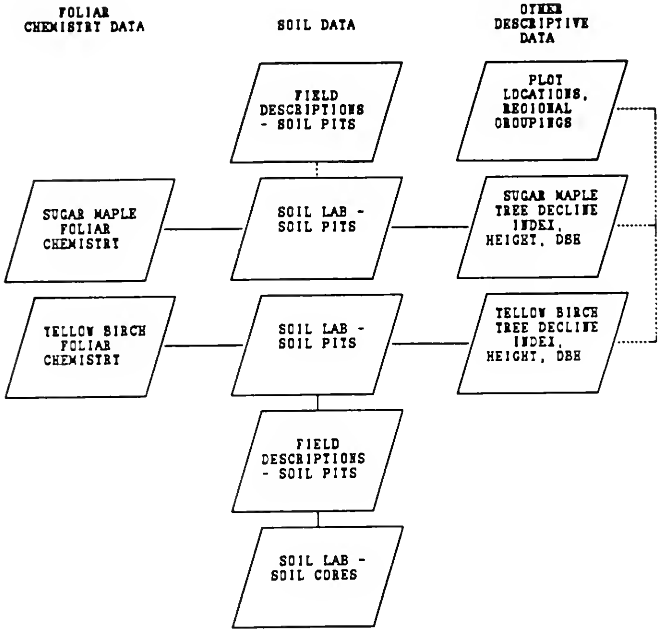
After completion of the chemical analyses, data files containing the sugar maple and yellow birch foliar chemistry, the soil pit and soil core chemistry were prepared by the Ministry of the Environment and forwarded to Ecological Services Limited. Files were provided by MOE as Lotus 1-2-3 spreadsheets, and dBase III database files.

Additional files were created containing: the field descriptions of the soil pits, geographic data related to the location of the sample plots; tree decline indices, heights and DBH for each yellow birch tree sampled; the mean decline indices for sugar maple for each plot (from the 1986 Hardwood Decline Survey Assessment results); plus the heights, and DBH for each sugar maple tree sampled (Figure 2).

All of the soil and foliar chemistry data files were examined to identify and correct data entry errors. In addition, the laboratory remarks associated with each chemical datum were examined to determine values in the data set which were below the detection limits of the laboratory procedures used. In the original data supplied, these values were coded as less than the detection limit. Following discussions with the Ministry of the Environment, these values were assigned a value of one-half the detection limit for each attribute. The number of values which

FIGURE 2

LINKAGES BETWEEN DATASETS PREPARED FOR THE SOIL AND FOLIAGE CHEMISTRY ANALYSES



were at or below the detection limits were also counted to assess the reliability of the mean estimates of foliar and soil element concentrations for each plot.

The tree decline index data, mensurational data, and the field soil data recorded for each soil pit were merged with the soil and foliar chemistry files in order to simplify correlation of these attributes in subsequent analyses. Soil attributes coded into the soil chemistry data sets included depth to bedrock, the thickness of each soil horizon and soil moisture regime. For the yellow birch foliar samples, the height, DBH, and decline index for each sampled tree was available, and these were merged into the yellow birch foliage chemistry data set. For the sugar maple sampling, which was conducted in 1986, tree decline indices were not assessed for each of the sampled trees. Therefore, the mean decline index, height, and DBH, for all sugar maples within the Hardwood Decline plot in which the sampling was conducted, were merged into the sugar maple foliage chemistry data set.

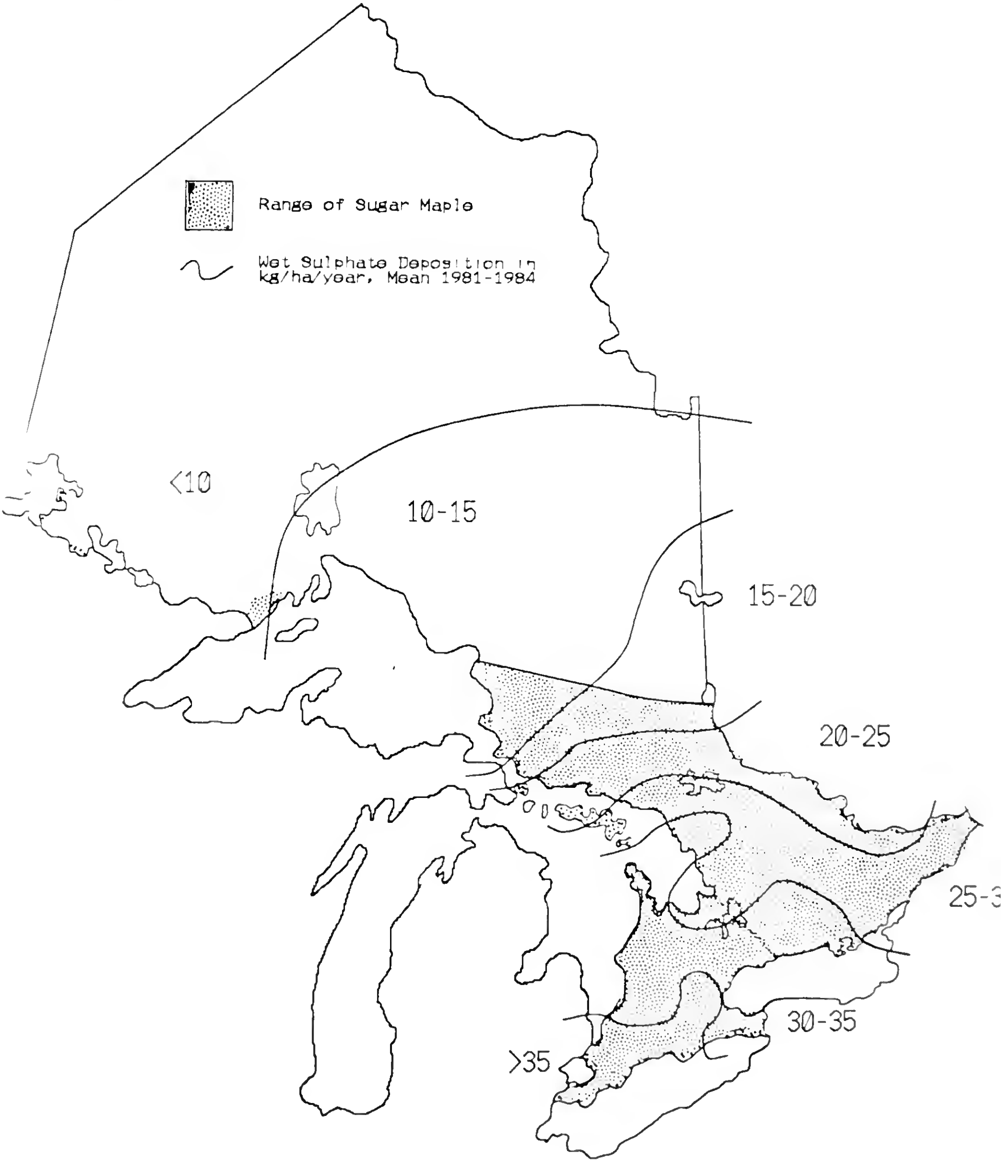
Lotus spreadsheets and the database manager Reflex were used to generate basic statistics for each plot, and for various geographic groupings used to assess regional patterns in the variation of soil and foliar chemistry. More detailed statistical analyses were accomplished by translating these modified files into a binary format suitable for use with the microcomputer statistics package SYSTAT (Wilkinson 1988).

The data analyses focused on three main objectives:

i) The assessment of variation in the soil and foliar chemistry, which involved determination of the sample sizes required to achieve an estimate of the mean values for each plot, for the various soil and foliage elements, within preset precision limits (plus or minus 10% and 20%). Basic statistics (means, minima, maxima) were also generated to indicate the range of values encountered throughout Ontario for the entire group of plots in the study. This information provides a baseline of foliar and soil element concentrations, which can be compared with the scientific literature, and provides a benchmark for future assessments.

ii) Basic statistics were also generated according to regional groupings, including plots aggregated according to their location within wet sulphate deposition loading zones in Ontario (Figure 3). Ontario Ministry of Natural Resources (OMNR) Administrative Districts were also chosen as a basis to examine regional patterns in foliar and soil element concentrations. The OMNR Districts provide a more detailed grouping of the plots which can be used to examine local differences in element concentration patterns. Also, the OMNR Districts had provided the original basis for the

FIGURE 3: The range of sugar maple and wet sulphate deposition isopleths, based on mean 1981-1984 loadings, in Ontario (Tang et al. 1986).



distribution of sampling for sugar maple in particular, and yellow birch to a lesser extent.

iii) Statistical analyses were performed to examine correlations between the levels of element concentrations in the soil compared to the associated chemistry of the foliage on each plot. Analyses were also directed towards: correlating attributes of the soil and foliar chemistry with the tree decline index values for individual yellow birch trees (or mean decline index values for Hardwood Decline plots, in the case of sugar maple); correlating chemistry of the foliage of both species with soil physical attributes, such as the thickness of individual horizons, depth of mineral soil to bedrock, and soil moisture regime; and towards correlating attributes of foliar chemistry to tree heights and diameters.

4.0 RESULTS AND DISCUSSION

4.1 Variability and Sampling Considerations

Estimates of the numbers of trees required to obtain estimates of the mean foliar element concentrations for each plot within preset limits of 10% and 20% of the mean, at the 95% confidence level, are listed in Table 2 for sugar maple, and in Table 3 for yellow birch. Sample sizes were estimated for each plot using the formula:

$$N = \frac{t^2 \times S^2}{d^2}$$

Where: t = t-value from statistical tables, at p=.05, with 4 degrees of freedom;
S^2 = variance of the sample of five trees;
d = the half width of the confidence interval; choosing either 10% or 20% of the mean of five samples.

The mean number of samples required and the range of sampling requirements (Tables 2 and 3) was then calculated from the individual estimates for each plot.

For both species, nitrogen (N) and sulphur (S) were the least variable elements in the foliage within plots. The sample size of five trees used in this study would, on average, yield an estimate of the mean foliage levels of N and S for each plot with approximately +/-20% precision. For sugar maple foliage, potassium (K) and calcium (Ca) levels, and for yellow birch foliage, phosphorus (P) and copper (Cu) levels, would also be estimated for each plot with approximately +/-20% precision with a sample size of five.

TABLE 2: Number of sugar maple foliage samples required to obtain an estimate of the mean within 10% and 20% at the 95% confidence level, based on 1986 sugar maple foliage sampling program (estimated from 5 samples per plot), for various foliage elements.

FOLIAGE ELEMENT	AVERAGE # SAMPLES TO ESTIMATE WITHIN 20% OF MEAN	MINIMUM SAMPLE SIZE ESTIMATE (20% OF MEAN)	MAXIMUM SAMPLE SIZE ESTIMATE (20% OF MEAN)	AVERAGE # SAMPLES TO ESTIMATE WITHIN 10% OF MEAN	MINIMUM SAMPLE SIZE ESTIMATE (10% OF MEAN)	MAXIMUM SAMPLE SIZE ESTIMATE (10% OF MEAN)
MACRONUTRIENTS						
N	4	1	32	17	1	126
P	8	1	56	32	1	220
K	5	1	14	19	2	55
Ca	5	1	22	22	1	86
Mg	7	1	27	27	2	108
S	4	1	20	16	1	78
MICRONUTRIENTS						
Cu	7	1	21	28	4	84
Fe	9	1	64	37	1	252
Mn	32	2	469	127	7	1854
Na	8	1	62	44	1	247
Zn	11	1	42	43	1	168
OTHER ELEMENTS						
Al	11	1	92	44	2	364
Cd	36	1	190	149	18	752
Ni	9	1	32	73	12	127
Pb	60	1	300	240	1	1185

TABLE 3: Number of samples required to obtain an estimate of the mean within 10% and 20% at the 95% confidence level, based on 1987 yellow birch foliage sampling. The number of samples needed were estimated for each plot. The table lists the average of these estimates, and the minimum and maximum estimate from all plots.

	NO. SAMPLES NEEDED FOR ESTIMATE WITHIN:					
	10% OF ACTUAL MEAN			20% OF ACTUAL MEAN		
FOLIAGE ELEMENT	MEAN ESTIMATED # SAMPLES	MIN # SAMPLES	MAX # SAMPLES	MEAN ESTIMATED # SAMPLES	MIN # SAMPLES	MAX # SAMPLES
MACRONUTRIENTS						
N	9	1	24	2	1	6
P	18	2	78	5	1	19
K	44	2	217	11	1	54
Ca	30	1	99	8	1	25
Mg	28	5	98	7	1	25
S	8	1	39	2	1	10
MICRONUTRIENTS						
Cu	12	1	50	3	1	12
Fe	28	3	329	7	1	82
Mn	107	11	461	27	3	115
Na	97	6	503	24	2	126
Zn	63	9	223	16	2	56
OTHER ELEMENTS						
Al	48	4	501	12	1	125
Cd	68	2	282	17	1	70
Ni	39	4	267	9	1	67
Pb	59	2	169	15	1	42

Approximately ten samples would be required to estimate the plot mean concentrations of foliar K, Ca, magnesium (Mg), iron (Fe), aluminium (Al), and nickel (Ni) for yellow birch within +/-20%. At least ten samples would also be required to estimate plot mean foliar concentrations of P, Mg, Cu, Fe, Na, Zn, Al and Ni for sugar maple within +/-20%.

Of all the nutrient elements, manganese (Mn) was the most variable for both species, requiring approximately 30 samples to obtain an estimate of the plot mean within +/-20%. Other elements including cadmium (Cd) and lead (Pb) were also quite variable and would require approximately 20 samples for yellow birch and 60 samples for sugar maple to obtain an estimate of the mean within 20%. However, as noted later, the results listed in Tables 2 and 3 for the elements Na, Cd, Ni and Pb must be interpreted cautiously, since a large number of observations were at or below the detection levels of the laboratory procedures. Also, the absolute magnitudes of the levels of these elements are quite small relative to the sensitivity of the chemical tests. Therefore, the variation associated with the mean levels of these elements is less meaningful.

Sample size estimates cannot be made from the soil pit samples since a maximum of two samples per plot were taken for each soil horizon. However, the soil cores sampled in conjunction with the yellow birch foliar sampling (five per plot) provide a means of

estimating soil variability (Table 4). Soil attributes within plots are extremely variable, with the exception of soil pH, which is estimated within +/-20% by five samples most of the time. Fifteen to 80 samples would be required to obtain estimates of all other soil elements within +/-20%. Soil N, organic carbon, Ni, and Pb were the least variable soil attributes, requiring approximately 20 samples, while K, Cu, Zn, and cation exchange capacity (CEC) were moderately variable, requiring 30 to 40 samples for +/-20% precision at the 95% confidence level.

The use of a fixed sampling depth interval of 0-30 cm for the soil core samples may have increased the variability of the results. Nutrient availability in the soil is strongly influenced by pH and organic matter content, which varies by soil horizon. Upper soil horizons in natural forest ecosystems typically have lower pH values and higher organic matter than subsurface horizons. Since thickness of A horizons can vary tremendously even within a small area, the use of a fixed sampling interval, although useful for comparison of equivalent soil volumes in the rooting zone, introduces an additional source of variation into the samples within each plot.

In future, it is recommended that core sampling be conducted by soil horizons, and that horizon depths be recorded, to minimize

TABLE 4: Number of samples required to obtain an estimate of the mean within 10% and 20% at the 95% confidence level, based on 1987 sampling of soil cores at yellow birch sites. The number of samples needed were estimated for each plot. The table lists the average of these estimates, and the minimum and maximum estimate from all plots.

	NO. SAMPLES NEEDED FOR ESTIMATE WITHIN:					
	10% OF PLOT MEAN			20% OF PLOT MEAN		
SOIL ATTRIBUTE	MEAN ESTIMATED SAMPLES	MIN # SAMPLES	MAX # SAMPLES	MEAN ESTIMATED SAMPLES	MIN # SAMPLES	MAX # SAMPLES
MACRONUTRIENTS						
N (Kjeldahl)	90	7	334	23	2	83
K	120	12	497	30	3	124
Ca	318	22	777	79	6	194
Mg	303	5	998	76	1	250
SO4	268	12	1410	67	3	352
MICRONUTRIENTS						
Cu	158	10	651	39	3	163
Fe (EDI)	142	10	640	35	3	160
Fe (EPY)	225	9	1021	56	2	255
Zn	120	5	775	30	1	194
OTHER ELEMENTS						
Al (ECA)	214	5	586	52	1	147
Al (EDI)	183	14	1538	46	3	384
Al (EPY)	160	11	1306	40	3	326
Al (ESC)	303	21	1765	73	1	441
Ni	91	8	470	23	2	117
Pb	64	6	230	16	1	58
OTHER SOIL ATTRIBUTES						
CEC	134	8	431	34	2	108
Organic C	101	3	380	25	1	95
pH (CaCl2)	7	1	37	2	1	9
pH (water)	6	1	29	1	1	7
% SAND	57	1	401	14	1	100
% SILT	108	4	651	27	1	163
% CLAY	151	14	397	38	3	99

ECA = CaCl2 extract
EDI = dithionite extract
EPY = pyrophosphate extract
ESC = Sodium Chloride extract

this problem. The soil pit versus soil core results are useful in that they indicate the extent of variation in profile development and soil chemistry that can be expressed within a single plot, and the consequent difficulties associated with soil sampling and interpretation of soil laboratory results.

4.2 Comparison of Results with Other Studies

Table 5 summarizes the overall mean, minimum and maximum levels of foliar elements for all the sugar maple and yellow birch trees sampled. Measurement units were modified from those of the original data to provide consistency and to simplify comparisons. Note that the results for non-nutrient elements must be interpreted cautiously, since a number of the observations were at or below detection limits (in the case of molybdenum (Mo), approximately 80% of the samples for both species).

Mean foliar element concentrations in this study generally follow the trend of values reported in the literature. For example, Hoyle (1965) reported yellow birch foliage sampled from a well-drained granitic till in New Hampshire to contain by weight 2.47% N, 0.19% P, 1.02% K, 0.97% Ca, 0.27% Mg, and 0.17% S, in foliage sampled in late August. The corresponding Ontario results for yellow birch foliar element levels, for samples collected from the lower crown, are: 2.85% N, 0.14% P, 1.59% K, 0.86% Ca, 0.23% Mg, and 0.16% S. For sugar maple foliar element levels, for samples collected from the lower crown, the Ontario results are: 2.15% N, 0.10% P, 1.06% K, 0.81% Ca, 0.12% Mg, and 0.22% S (Morrison 1985).

The mean results in Table 5 correspond very closely with those reported by Morrison (1985) for both sugar maple and yellow birch. Mean values for N, P, K, Mg, S, Cu, Fe, Mn and Zn from this study

TABLE 5: Summary of the overall average, minimum and maximum levels of nutrients and other elements in the sugar maple and yellow birch foliage samples.

FOLIAGE ELEMENT		Sugar Maple: MEAN	MIN	MAX	STANDARD DEVIATION	% of Samples At or Below Detection Limit	Yellow Birch: MEAN	MIN	MAX	STANDARD DEVIATION	% of Samples At or Below Detection Limit
MACRONUTRIENTS											
N	(%)	1.98	1.42	2.50	0.40	0	2.55	2.00	3.04	0.35	0
P	(%)	0.17	0.10	0.31	0.07	0	0.18	0.11	0.31	0.05	0
K	(%)	0.84	0.58	1.33	0.18	0	1.13	0.65	1.61	0.31	0
Ca	(%)	1.32	0.72	1.92	0.36	0	1.40	0.95	2.66	0.42	0
Mg	(%)	0.19	0.11	0.38	0.07	0	0.28	0.17	0.41	0.07	0
S	(%)	0.20	0.15	0.25	0.03	0	0.14	0.12	0.17	0.02	0
MICRONUTRIENTS											
Cu	(ppm)	5.4	3.6	7.3	1.3	0	6.3	4.3	7.9	1.1	0
Fe	(ppm)	84	39	208	79	0	98	66	208	36	0
Mn	(ppm)	755	82	2280	702	0	1717	203	5480	1276	0
Na	(ppm)	11.7	10.0	19.0	3.2	64	14.1	6.0	38.2	7.7	29
Zn	(ppm)	23.0	13.0	48.4	9.8	0	334.2	100.0	486.0	132.4	0
OTHER ELEMENTS											
Al	(ppm)	47	20	150	33	0	54	22	144	33	6
Cd	(ppm)	0.28	0.05	0.52	0.16	11	2.51	0.56	3.68	1.04	0
Cl	(%)	0.06	0.02	0.12	0.03	0	0.01	0.01	0.06	0.01	80
Mo	(ppm)	0.33	0.25	0.90	0.09	79	0.48	0.25	0.80	0.08	77
Ni	(ppm)	1.44	0.50	6.24	1.22	46	2.65	1.00	5.76	1.59	26
Pb	(ppm)	1.55	0.50	2.80	1.13	39	2.26	1.00	4.26	0.88	30

are within 20% of those reported by Morrison. The mean values for Ca from this study are higher than those reported by Morrison. This may be due to the tendency for Ca to accumulate in the foliage of both tree species over the growing season (Morrison 1985), coupled with the relatively late time of foliage sampling in this study (mid to late August for northern Ontario plots, and late August to mid September for southern Ontario plots).

In general, foliar element concentrations were higher in yellow birch than in sugar maple. Yellow birch element concentrations were higher by about 10-50% for N, P, K, Ca, Mg, Cu, Fe, Al, Na, Mo and Pb; about 100%-150% greater for Ni and Mn; and 10-20 times greater for Zn and Cd. The tendency of yellow birch to accumulate Zn and Cd in the foliage and other biomass has been previously reported in the literature (Whittaker et al. 1979; Hogan and Morrison 1988).

4.3 Correlation of Soil and Foliar Chemistry

In general, soil features were not strongly correlated with foliar chemistry. Correlation r-values, although significant, were mostly less than 0.5. However, correlations (Pearson's method) between foliar and soil chemistry and other attributes were useful in that they indicated possible relationships between soil and foliar features. Correlations between foliage element levels and soil features are summarized in Table 6 for yellow birch foliage versus the corresponding soil core samples, and in Tables 7 and 8 for sugar maple foliage versus soil attributes of the A and B horizons sampled from the corresponding soil pits.

Uptake of nutrient elements by trees is not necessarily related to their needs for these elements. Hence, one might expect the strongest relationships between soil levels and uptake to occur where supply of the element was limited. A direct, strong correlation between soil and foliar element levels (r-value = 0.91) occurs only for Mg. Hence, soil Mg levels may be limiting for a number of the sampled plots. Soil levels of Ca are also strongly related to foliage levels for sugar maple, and are weakly correlated for yellow birch.

Of all the soil attributes, pH values provided the strongest correlations with the largest number of foliar element levels. For yellow birch, pH was positively correlated with foliar Fe, Mg,

TABLE 6: Pearson correlations between yellow birch foliar chemistry and chemistry of the soil core samples.

FOLIAR ELEMENT	POSITIVE CORRELATIONS p=0.01	p=0.05	NEGATIVE CORRELATIONS p=0.01	p=0.05
MACRONUTRIENTS				
N		Fe		
P				Fe
K				
Ca	Ca,CEC,Pb,pH	Mg,Sand	Al,Fe,OrgC	Silt
Mg	Ca,CEC,Cu,Mg,Pb,pH,Zn	Ni	Al,Fe	Silt
S				
MICRONUTRIENTS				
Cu	Al,Fe	Silt	Ca,pH	CEC,Mg
Fe		pH,Sand	N,OrgC,SO4	Al,Fe,K,Silt
Mn	Al		Ca,CEC,pH	
Na				Fe
Zn	Al,Fe	Silt	Ca,CEC,Pb,pH	
OTHER ELEMENTS				
Al		pH,Sand	SO4	Al,Fe,N,OrgC,Silt
Cd	Al	Fe,Silt	Ca,CEC,Mg,Pb,pH	Sand
Cl	pH		Fe	Al
Mo		Sand	N	Al,Zn,Silt
Ni		Al,Silt	pH	Ca,Pb,Sand
Pb			Pb	

NOTES: CEC = cation exchange capacity; depth = soil depth to bedrock.

TABLE 7: Pearson correlations between sugar maple foliar chemistry and 'A' horizon soil chemistry.

FOLIAR ELEMENT	POSITIVE CORRELATIONS p=0.01	p=0.05	NEGATIVE CORRELATIONS p=0.01	p=0.05
MACRONUTRIENTS				
N		depth		OrgC,N
P	depth,Silt		Sand	
K	moisture regime	Silt,N		pH
Ca	pH,CEC,Ca		Al	Fe
Mg	pH,CEC,Ca,Mg	Zn	Al	Fe
S		depth,Silt,Ni		pH,Sand
MICRONUTRIENTS				
Cu				pH
Fe		depth		
Mn	Al		pH	CEC,Ca,Mg
Na				
Zn	Al	Silt,SO4	pH	CEC,Ca
OTHER ELEMENTS				
Al		depth		
Cd	Al			pH,Ca
Cl	SO4	Pb		
Mo	K,Al,SO4,Ni,Pb			
Ni	pH,Silt,SO4,Ni	K	Sand	
Pb	Al,SO4	depth,K,Pb,N		Sand,OrgC

NOTES: CEC = cation exchange capacity; depth = soil depth to bedrock.

TABLE 8: Pearson correlations between sugar maple foliar chemistry and 'B' horizon soil chemistry.

FOLIAR ELEMENT	POSITIVE CORRELATIONS p=0.01	p=0.05	NEGATIVE CORRELATIONS p=0.01	p=0.05
MACRONUTRIENTS				
N		depth		
P	depth,Silt		Sand	OrgC
K	MR	Ni	pH	Ca
Ca	pH		OrgC,Al	Fe
Mg	pH	Clay,CEC,Ca,Mg,Pb	Al	OrgC,Fe
S		depth,Al	pH	Ca
MICRONUTRIENTS				
Cu				Cu
Fe		depth		
Mn	OrgC,Al	Fe	pH,CEC,Ca	Mg
Na				
Zn	Al		pH,CEC,Ca	Mg
OTHER ELEMENTS				
Al		depth		
Cd	Al		pH,CEC,Ca	
Cl				
Mo	SO4	Al		
Ni	Silt,Al		pH	Sand,Ca
Pb		depth,Al		pH

NOTES: CEC = cation exchange capacity; depth = soil depth to bedrock.

Ca and Al (i.e. low pH values were associated with lower foliar levels); and negatively correlated with Cu, Mn, Zn, Cd and Ni (i.e. low pH values correspond with higher foliar levels of these elements).

For sugar maple the pattern was similar: pH was positively correlated with foliar Ca and Mg, and negatively correlated with K, S, Cu, Mn, Zn, Cd, Pb and Ni. In other words, soils with low pH tended to correspond to lower sugar maple foliage levels of Ca and Mg; and to higher levels of K, S, Cu, Mn, Zn, Cd, Pb and Ni.

These trends were examined further by generating mean values for foliage element levels for yellow birch (Table 9) and for sugar maple (Table 10) according to defined ranges of soil pH values in the uppermost soil (A) horizon. For comparison, Tables 11 and 12 summarize the mean soil chemistry for the soil samples taken in conjunction with the foliar samples for each tree species.

Tables 9 and 10 confirm strong increasing trends for Ca and Mg with increasing pH, and strong decreasing trends for Mn and Zn with increasing pH for both tree species. The decreasing trend for Cu with increasing pH is more pronounced for yellow birch foliage than for sugar maple foliage. In general, the largest differences in mean foliage element levels occur for the lowest pH class (less than 4.5) and for pH values greater than 6.0.

TABLE 9: Mean foliage chemistry for yellow birch according to classes of soil pH (water) in the uppermost mineral soil 'A' horizon.

FOLIAGE ELEMENT		pH Ranges in the A Horizon					
		<4.5	4.5-4.9	5.0-5.4	5.5-5.9	6.0-6.9	7.0 +
MACRONUTRIENTS							
N	(%)	2.58	2.63	2.43	2.48	2.42	2.48
P	(%)	1.47	1.90	1.91	1.25	1.96	1.99
K	(%)	1.09	1.16	1.32	0.94	1.03	1.13
Ca	(%)	1.13	1.29	1.44	1.73	2.00	1.71
Mg	(%)	0.24	0.29	0.28	0.37	0.32	0.29
S	(%)	0.14	0.16	0.14	0.13	0.14	0.16
MICRONUTRIENTS							
Cu	(ppm)	6.7	6.4	6.5	5.6	5.5	5.6
Fe	(ppm)	87	90	88	97	135	141
Mn	(ppm)	2205	2131	1431	618	671	381
Na	(ppm)	10.6	14.0	20.3	9.3	18.3	15.4
Zn	(ppm)	343	378	415	191	237	165
OTHER ELEMENTS							
Al	(ppm)	49	46	43	56	88	92
Cd	(ppm)	2.79	2.87	2.67	1.55	1.58	1.28
Cl	(%)	0.01	0.01	0.02	0.02	0.02	0.02
Mo	(ppm)	0.44	0.50	0.50	0.50	0.47	0.50
Ni	(ppm)	2.78	3.34	2.84	1.35	1.18	1.10
Pb	(ppm)	1.93	2.61	2.67	1.29	2.17	1.68

TABLE 10: Mean foliage chemistry for sugar maple according to classes of soil pH (water) in the uppermost mineral soil 'A' horizon.

FOLIAGE ELEMENT		pH Ranges in the A Horizon					
		<4.5	4.5–4.9	5.0–5.4	5.5–5.9	6.0–6.9	7.0 +
MACRONUTRIENTS							
N	(%)	2.11	1.92	1.95	1.87	2.09	1.86
P	(%)	1.82	1.49	1.78	1.76	1.64	1.61
K	(%)	0.88	0.83	1.00	0.81	0.78	0.69
Ca	(%)	1.19	1.15	1.10	1.43	1.53	1.59
Mg	(%)	0.18	0.16	0.17	0.18	0.23	0.24
S	(%)	0.22	0.19	0.20	0.18	0.19	0.19
MICRONUTRIENTS							
Cu	(ppm)	5.5	5.6	6.4	4.8	5.0	5.2
Fe	(ppm)	84	173	58	82	88	87
Mn	(ppm)	1384	845	640	611	246	525
Na	(ppm)	11.2	11.6	12.9	11.1	12.5	11.1
Zn	(ppm)	31	25	24	19	17	19
OTHER ELEMENTS							
Al	(ppm)	46	87	30	38	49	50
Cd	(ppm)	0.37	0.31	0.28	0.25	0.20	0.26
Cl	(%)	0.06	0.05	0.05	0.06	0.07	0.07
Mo	(ppm)	0.56	0.55	0.51	0.52	0.53	0.51
Ni	(ppm)	2.94	1.80	1.63	1.31	1.00	1.08
Pb	(ppm)	1.78	1.80	1.36	1.54	1.60	1.16

TABLE 11: Mean soil chemistry according to ranges of pH values, in the 'A' horizon, from the soil pits sampled in conjunction with the yellow birch foliage sampling, 1987.

SOIL ATTRIBUTE		pH Ranges in the A Horizon					
		<4.5	4.5–4.9	5.0–5.4	5.5–5.9	6.0–6.9	7.0 +
% Organic Carbon		4.28	3.74	3.63	2.53	2.91	2.84
Cation Exchange Capacity	(meq/100g)	3.50	2.60	5.17	6.79	11.85	13.42
pH (water)		4.3	4.7	5.2	5.7	6.5	7.5
pH (CaCl2 buffered)		3.9	4.2	4.6	5.1	5.9	7.0
MACRONUTRIENTS							
N	(%)	2.49	2.32	3.09	1.87	2.52	2.10
K	(meq/100g)	0.08	0.07	0.06	0.07	0.15	0.10
Ca	(meq/100g)	0.97	0.98	3.85	6.03	10.16	12.01
Mg	(meq/100g)	0.18	0.21	0.41	0.64	1.44	1.26
SO_4	(ppm)	27.1	21.6	32.7	19.9	30.5	24.7
MICRONUTRIENTS							
Fe (EPY)	(%)	1.22	1.18	1.09	1.02	1.03	1.06
Fe (EDI)	(%)	0.78	0.67	0.49	0.32	0.21	0.17
Cu	(ppm)	7.7	10.4	11.3	12.9	20.2	18.1
Zn	(ppm)	36	40	55	52	73	77
OTHER ELEMENTS							
Al (ESC)	(meq/100g)	2.27	1.34	0.85	0.07	0.11	0.06
Al (ECA)	(ppm)	24.2	17.5	7.7	2.1	1.2	0.4
Al (EPY)	(%)	0.69	0.60	0.48	0.24	0.18	0.11
Al (EDI)	(%)	0.74	0.68	0.60	0.29	0.28	0.16
Ni	(ppm)	10.1	12.1	13.6	14.6	16.8	18.1
Pb	(ppm)	19.0	15.6	14.6	26.5	19.6	38.5

NOTES: ECA = CaCl2 extract; EDI = dithionite extract; EPY = pyrophosphate extract; ESC = NaCl extract.

TABLE 12: Mean soil chemistry according to ranges of pH values, in the 'A' horizon, from the soil pits sampled in conjunction with the sugar maple foliage sampling, 1986.

SOIL ATTRIBUTE		pH Ranges in the A Horizon <4.5	4.5–4.9	5.0–5.4	5.5–5.9	6.0–6.9	7.0 +
% Organic Carbon		3.90	6.13	4.15	3.60	4.66	3.48
Cation Exchange Capacity	(meq/100g)	6.72	6.45	8.03	8.46	18.46	18.08
pH (water)		4.1	4.8	5.1	5.7	6.6	7.5
pH (CaCl2 buffered)		3.8	4.3	4.6	5.2	6.3	7.1
MACRONUTRIENTS							
N	(%)	3.19	4.38	2.95	2.76	4.00	3.10
K	(meq/100g)	0.18	0.16	0.11	0.09	0.22	0.10
Ca	(meq/100g)	4.04	3.91	6.22	7.40	15.24	15.06
Mg	(meq/100g)	0.65	0.58	0.96	0.88	2.97	2.87
SO_4	(ppm)	76.4	42.0	36.4	31.6	52.2	35.6
MICRONUTRIENTS							
Fe (EPY)	(%)	0.92	1.90	1.37	1.07	1.26	1.15
Fe (EDI)	(%)	0.43	1.34	0.57	0.35	0.21	0.25
Cu	(ppm)	12.8	10.3	18.7	8.8	19.9	13.2
Zn	(ppm)	54	44	89	71	100	73
OTHER ELEMENTS							
Al (ESC)	(meq/100g)	1.85	1.80	0.74	0.10	0.03	0.05
Al (ECA)	(ppm)	22.9	18.2	8.2	2.4	0.4	0.3
Al (EPY)	(%)	0.19	0.59	0.47	0.20	0.12	0.24
Al (EDI)	(%)	0.21	0.69	0.56	0.25	0.21	0.29
Ni	(ppm)	18.0	10.6	22.1	11.7	13.8	14.4
Pb	(ppm)	27.5	21.5	19.4	15.3	40.8	24.6

NOTES: ECA = CaCl2 extract; EDI = dithionite extract; EPY = pyrophosphate extract; ESC = NaCl extract.

Within the soil (Tables 11 and 12), pH is strongly positively correlated with cation exchange capacity, Ca, Mg, Cu and Zn, and negatively correlated with Fe and Al. Ni and Pb levels show a slight increasing trend with soil pH, but this must be interpreted cautiously due to the number of samples which were at or below detection limits for these elements. Soil N, K and SO4 levels do not appear to be directly related to soil pH.

Soil depth to bedrock was positively correlated to foliar N, Al and Fe levels (as well as foliar P, S and Fe), but was negatively correlated with soil levels of N and Al. This suggests that with regard to uptake of some nutrient elements into the foliage, the volume of soil available to the tree for rooting may be equally important as the absolute concentrations of elements in the soil.

Organic matter in soils tends to retain nutrients and other elements through the formation of humic acid complexes, and was found to be correlated with several elements in the soil and the foliage of both tree species. Soil organic carbon content was positively correlated with both soil and foliar N and Pb levels. Organic carbon was also positively correlated with soil K, S, Fe and Al; but was negatively correlated with foliar K; unrelated to foliar S, Fe and Al; and was also negatively correlated with foliar Ca and Mg.

Thickness of the A horizon was positively correlated with soil pH.

Since pH is correlated with the levels of many soil elements, this supports the methodology of sampling soils according to horizons for estimating chemical properties and comparing these values between sites.

4.4 Correlation of Tree Decline Index, Tree Height, and Tree Diameter with Soil and Foliar Chemistry

Tree decline indices were significantly correlated (at probability level p=0.10 or better) with several soil and vegetation attributes (Table 13). The decline index for sugar maple was positively correlated with soil organic carbon, Al, and Fe; and negatively correlated with soil nitrogen and 'B' horizon pH values. Decline index for yellow birch was not significantly correlated with any soil attributes at p=0.10, although soil pH provided the 'best' correlation with decline index, at p=0.123.

For both species, decline index was positively correlated with foliar Mn. Yellow birch decline index was also positively correlated with foliar Cd and Ni, while sugar maple decline index was positively correlated with foliar Pb. Yellow birch decline index was negatively correlated with foliar K, Ca, Cu, Fe, Al and Cl. In other words, higher decline indices (and hence, poorer relative tree condition) for both species tended to be associated with lower soil pH values, and higher foliar Mn levels. For yellow birch, higher decline indices tended to be associated with lower foliar levels of K, Ca, Cu, Fe, Al and Cl levels, and higher foliar Cd and Ni levels.

Tree height and diameter were not correlated strongly or consistently with the foliar concentrations of either tree species.

TABLE 13: Correlations between sugar maple and yellow birch decline indices and soil and foliar chemistry.

FOLIAGE/SOIL ELEMENT	YELLOW BIRCH DECLINE INDEX VS: YELLOW BIRCH FOLIAR CHEM.		YELLOW BIRCH DECLINE INDEX VS: SOIL CORES CHEMISTRY		SUGAR MAPLE DECLINE INDEX VS: SUGAR MAPLE FOLIAR CHEM.		SUGAR MAPLE DECLINE INDEX VS: 'A' HORIZON CHEMISTRY		SUGAR MAPLE DECLINE INDEX VS: 'B' HORIZON CHEMISTRY	
MACRONUTRIENTS										
N	0.304	* ns	0.483	ns	0.639	* ns	0.199	ns	<.001	*.01
P	0.598	* ns	na		0.796	* ns	na		na	
K	0.078	*.10	0.379	ns	0.628	* ns	0.361	ns	0.922	* ns
Ca	0.048	*.05	0.378	ns	0.130	* ns	0.264	* ns	0.490	* ns
Mg	0.510	* ns	0.641	ns	0.741	* ns	0.390	ns	0.875	ns
S	0.060	* ns	0.873	ns	0.890	ns	0.564	ns	0.028	.05
MICRONUTRIENTS										
Cu	0.804	* ns	0.476	ns	0.643	ns	0.351	ns	0.703	ns
Fe	0.051	*.10	0.361	ns	0.694	ns	<.001	.01	0.001	.01
Mn	0.002	.01	na		0.064	.10	na		na	
Na	0.285	* ns	na		0.530	* ns	na		na	
Zn	0.249	ns	0.985	ns	0.122	ns	0.160	ns	0.101	ns
OTHER ELEMENTS										
Al	0.078	*.10	0.347	ns	0.726	ns	0.002	.01	0.002	.01
Cd	0.026	.05	na		0.207	ns	na		na	
Cr	0.045	*.05	na		0.163	* ns	na		na	
Mo	0.609	ns	na		0.152	ns	na		na	
Ni	0.010	.01	0.734	ns	0.452	ns	0.602	ns	0.895	ns
Pb	0.761	* ns	0.595	ns	0.057	.10	0.547	ns	0.182	ns
pH (water)	na		0.123	* ns	na		0.106	* ns	0.068	*.10
Organic Carbon	na		0.448	ns	na		0.037	.05	0.004	.01
Cat. Exch. Cap.	na		0.532	* ns	na		0.660	* ns	0.807	* ns

Note: * = negative correlation
.01 = significant at p=.01
.05 = significant at p=.05
.10 = significant at p=.10
ns = not significant at p=.10

4.5 Regional Patterns in Soil and Foliar Chemistry

Tables of mean element concentrations for sugar maple foliage and yellow birch foliage were generated for plots located within wet sulphate deposition loading zones in Ontario (Appendix 4). Mean decline indices for sugar maple and yellow birch for the plots within each loading zone are included in each table for comparison. Mean values for soil chemistry and certain physical properties, including depth to rock, horizon thicknesses, soil moisture regime, and particle size distributions for the clay, silt and sand fractions were also summarized by loading zones for soil 'A' horizons, soil 'B' horizons and for the soil core samples (Appendix 4).

Patterns of soil and foliar element concentrations and tree decline index do not follow the trend that might be expected in regards to levels of wet sulphate deposition; i.e., increasing acidity and possibly increasing soil Al levels with increasing deposition. This is perhaps partly due to the fact that 'natural' levels of acidity in the soil within the study area tend to be greatest in the areas of lowest deposition (the granitic shallow tills of the Cambrian Shield). Conversely, in the highest loading zones, the soils are generally deeper, and better buffered due to their limestone base (Cowell 1986).

Levels of Cd in yellow birch appear to increase in conjunction with the wet sulphate deposition levels. The reason for this is

unknown. However, levels of atmospheric Cd deposition are similar to the patterns for wet sulphate deposition (Tang et al. 1986). Yellow birch may tend to accumulate Cd, possibly through foliar absorption (Hogan and Morrison 1988); however, this species is known to be a natural accumulator of zinc and cadmium.

OMNR Districts provide a basis for examining regional differences in more detail. Hence, mean values for soil and foliage chemistry were generated for all samples located within each OMNR Administrative District. Summaries showing the mean levels for soil chemistry for the A, B and C mineral soil horizons and corresponding foliage chemistry (where applicable) for each District are included in Appendix 5, for both sugar maple and yellow birch samples, for the following attributes:

- N, P and K
- Ca and Mg
- pH, % Organic Carbon and Cation Exchange Capacity
- Aluminium
- Ni, Pb and Cd

These summaries are intended mainly to provide baseline values against which future samples can be compared. However, several points are worth noting. In general, between Districts, foliar levels of most elements are not well correlated with corresponding levels in the soils, with the exception of Ca and Mg.

Soil chemistry in each District reflects the natural geochemistry

of the locale. Soil chemistry varies across the province depending on local geology and soil parent materials. For example, soil levels of Ni are relatively high in the Sudbury District (6th out of 27 Districts). Corresponding mean foliage levels of Ni in Sudbury are the highest of all Districts for both sugar maple and yellow birch.

Mean soil pH levels reflect differences between the acidic granitic rock base of the Canadian shield, and the limestone base present in several southern Ontario Districts. Chatham, Niagara and Owen Sound Districts show an acidified cap (with pH values ranging from 3.9 to 4.5) over limestone-based parent materials (with pH values ranging from 7.4 to 7.6). The Aylmer, Chatham, Cambridge, Cornwall, Huronia, Lindsay, Maple, Napanee, Simcoe, Espanola, and Wingham Districts generally have neutral pH values greater than 6.0 in all soil horizons. The Algonquin, Bancroft, Bracebridge, Brockville, Carleton Place, Espanola, Minden, Parry Sound, Pembroke, Thunder Bay and Tweed Districts have intermediate soil pH values in all horizons, ranging from 4.5 to 6.0. Blind River, North Bay, Sault Ste. Marie and Sudbury Districts have very acidic pH values, less than 4.5 in the A horizons and less than 5.0 in the B horizons.

5.0 SUMMARY

Based on results of this study, suggested sample sizes to obtain a 95% confidence interval within 20% of the mean for foliage element levels within a stand are as follows:

Species	Foliage Elements	Minimum No. of Trees
Yellow birch	N, P, S, Cu	5
	K, Ca, Mg, Fe, Al, Ni	10
	Zn, Cd, Pb	15
	Mn, Na	25+
Sugar maple	N, K, Ca, S	5
	P, Mg, Cu, Fe, Na, Zn, Al, Ni	10
	Mn	30
	Cd, Pb	30+

Sample sizes can be reduced if a lower probability level (e.g. p=0.10), or a larger confidence interval about the mean can be accepted.

In general, element levels were higher in yellow birch foliage than for sugar maple, especially for Zn and Cd. This confirms the trend reported in the literature for yellow birch to accumulate these elements. Levels of Ni and Mn were also somewhat higher for the yellow birch foliage.

Soil chemistry was more variable than the foliar chemistry. For most soil attributes, minimum sample sizes ranging from 20 to 40 to obtain an estimate of the mean within 20% were estimated. Sampling by soil horizons rather than fixed depth intervals may help to reduce variability and reduce the number of samples

required.

Correlations between foliar chemistry and soil chemistry, using either the soil cores data (average of five samples) or the soil data by horizon from the soil pits (single samples or an average of two samples) gave essentially the same results. Hence, if the objective of a study is to examine broad relationships and trends in the soil data, large sample sizes may not be necessary. If the purpose of a study is to generate precise estimates of average soil properties on a site by site basis, the amount of sampling to be done will be dictated by practical limits, particularly time and the high cost of soil laboratory analyses.

Correlations between soil and foliage element levels showed that soil pH is the soil attribute most consistently correlated with the foliar element levels, along with soil Al, which is highly correlated with pH. In general, low pH soils tend to be associated with higher levels of soil Al, Fe, Ni and Pb; and lower levels of Ca, Mg, Cu and Zn, and lower CEC. The foliage of trees of both species on soils with lower pH values tended to have lower levels of Ca and Mg, and higher levels of Mn, Cu and Zn. Yellow birch foliage also tended to have lower N levels on low pH soils.

Increasing tree decline index for both tree species was correlated with lower soil pH values and higher foliar Mn levels. For yellow birch, higher decline indices tended to be associated with lower

foliar K, Ca, S, Fe and Al levels, and higher foliar Cd and Ni levels. For sugar maple, higher decline indices tended to be associated with higher foliar Pb levels.

The mean values for the foliage chemistry of both yellow birch and sugar maple reported in this study generally follow the trend of values reported in the literature in both Ontario and the northeastern United States. Variation occurs between individual plots, but this variation was found to correspond well with regional distribution patterns of soil and foliar chemistry. Regional patterns can be attributed largely to broad differences in local geochemistry and soil parent materials.

In general, there do not appear to be any signs of serious deficiencies or nutrient imbalances in the sites studied, although acceptable levels of potentially toxic elements such as Al, Ni, Cd, and Pb are largely unknown. The potential effects of atmospheric inputs on the soil and foliar element levels reported are also not known, and interpretation of pollution loading levels is complicated by the presence of many different soil types in each loading zone, and the relatively small number of plots sampled for this project.

Cause-and-effect relationships between soil features and foliar chemistry, and between atmospheric deposition levels and soil and foliage chemistry, cannot be established from the results of this

study. Correlations between soil and foliar chemistry and tree decline indices have been discussed in this report. These indicate trends in the relationships between these attributes, which may be helpful in identifying and designing future research programs. The mean values for soil and foliage attributes reported herein are, hence, intended mainly to provide baseline values, that is, a "snapshot" of conditions at the time of sampling. This may prove useful as the basis for comparison with future work of a similar nature.

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APPENDIX 1

Summary of the locations of
foliage and soil sample plots.

APPENDIX 1: Locations of the sugar maple (sampled 1986) and yellow birch (sampled 1987) foliage and soil sampling plots in Ontario.

Plot Number	Foliage Sampling	Forest Region	Forest Sector	MNR District	Township	Air Photo No.	Lot	Conc.	FRI Stand	Ownership	NTS 1:50000 Map Sheet	UTM Coordinates	
A-002	By, Mh	GLSL	4B	BRACEBRIDGE	BETHUNE	n/a	n/a	n/a	243	Public	31E/11 BURK'S FALLS	17T 646200E	5048250N
A-003	By	GLSL	4B	NORTH BAY	STEWART	77-4623-100	n/a	n/a	81	Public	31L/11 TEMISCAMING	17T 620200E	5155050N
A-004	By, Mh	GLSL	4B	NORTH BAY	MERRICK	77-4620-65-188	n/a	n/a	83	Public	31L/6 NORTH BAY	17T 616000E	5147250N
A-005	By	GLSL	4B	BRACEBRIDGE	BUTT	n/a	n/a	n/a	70	Public	31E/11 BURK'S FALLS	17T 650200E	5065500N
A-006	By	GLSL	2	CORNWALL	HAWKSBURY	78-4539-192-104	15	I	n/a	Public	31G/9 LACHUTE	18T 542300E	5045000N
A-008	By, Mh	GLSL	2	CORNWALL	CHARLOTTENBURGH	78-4509-113-135	2	I	n/a	Public	31G/2 & 31B/15 CORNWALL	18T 533400E	4993650N
A-009	Mh	GLSL	4B	PEMBROKE	ROSS	76-4529-10-253	n/a	n/a	47	Public	31F/10 COBDEN	18T 363250E	5060000N
A-011	Mh	GLSL	2	CARLETON PLACE	LANARK	n/a	6	IX	n/a	Public	31F/1 CARLETON PLACE	18T 397500E	4993100N
A-012	Mh	GLSL	2	BROCKVILLE	OXFORD	n/a	2	VII	n/a	Public	31B/13 MERRICKVILLE	18T 448400E	4970250N
A-013	By, Mh	GLSL	10	SAULT STE. MARIE	DAUMONT	81-4633-39-40	n/a	n/a	289	Public	41J/13 RANGER LAKE	17T 279850E	5185500N
A-014	Mh	GLSL	2	CORNWALL	OSNABRUCK	78-4501-155-182	37	V	n/a	Public	31G/3 WINCHESTER	18T 491400E	4985900N
A-015	By	GLSL	10	WAWA	LABONTE	n/a	n/a	n/a	216	Public	41N/7 AGAWA BAY	16T 685250E	5246300N
A-017	Mh	GLSL	4D	PARRY SOUND	CHRISTIE	77-4517-34-35	n/a	n/a	113	Public	31E/5 ORRVILLE	17T 595000E	5275000N
A-018	By	GLSL	4D	PARRY SOUND	MONTEITH	77-4519-46-53	n/a	n/a	100	Public	31E/5 ORRVILLE	17T 609500E	5325000N
A-020	By, Mh	GLSL	1	HURONIA	MULMUR	66-4403-102-43	2	I	n/a	Public	41A/1 DUNDALK	17T 568900E	4883400N
A-021	By	GLSL	4B	HURONIA	MULMUR	66-4403-102-44	12	III	n/a	Public	41A/1 DUNDALK	17T 565650E	4889100N
A-023	By	GLSL	4B	HURONIA	MEDONTE	n/a	45	II	n/a	Public	31D/12 ELMVALE	17T 601650E	4935300N
A-024	By, Mh	GLSL	4B	HURONIA	MEDONTE	n/a	45	II	n/a	Public	31D/12 ELMVALE	17T 601450E	4935050N
A-027	By, Mh	GLSL	1	SUDBURY	KILLARNEY	n/a	n/a	n/a	147	Public	41I/13 LAKE PANACHE	17T 476325E	5099375N
A-030	Mh	GLSL	4E	ESPANOLA	GOUGH	n/a	n/a	n/a	105	Public	41I/5 ESPANOLA	17T 427250E	5129750N
A-033	By, Mh	GLSL	10	BLIND RIVER	SCARFE	81-4613-02-59	n/a	n/a	55	Public	41J/6 IRON BRIDGE	17T 341250E	5131000N
A-035	By	GLSL	10	BLIND RIVER	WELLS	81-4616-03-37	n/a	n/a	198	Public	41J/6 IRON BRIDGE	17T 312250E	5139250N
A-037	By	GLSL	10	SAULT STE. MARIE	ABERDEEN	81-4622-36-37	n/a	n/a	30	Public	41J/12 ECHO LAKE	17T 279000E	5154600N
A-039	By	GLSL	10	SAULT STE. MARIE	WISHART	81-4702-19-20	n/a	n/a	10	Public	41N/1 BATCHEWANA	16T 696500E	5213800N
A-040	By	GLSL	10	SAULT STE. MARIE	FISHER	81-4640-04-05	n/a	n/a	24	Public	41K/15 PANCAKE BAY	16T 688900E	5204500N
A-043	Mh	DCD	1	NIAGARA	BERTIE	78-4263-46-164	1	X	170	Private	30L/14 WELLAND	17T 660500E	4752100N
A-045	Mh	DCD	1	CAMBRIDGE	NASSAGAWEYA	n/a	6	V	11	Public	30M/5 BURLINGTON	17T 583250E	4816450N
A-046	By	DCD	1	SIMCOE	NORFOLK	78-4248-211-182	3	VIII	7	Public	40I/10 PORT BURWELL	17T 531825E	4725450N
A-047	By, Mh	DCD	1	AYLMER	MALAHIDE	78-4251-203-134	4	V	7	Public	40I/11 PORT STANLEY	17T 498600E	4731400N
A-048	Mh	DCD	1	SIMCOE	NORWICH	78-4263-180-145	27	IX	2	Public	40I/15 TILLSONBURG	17T 523600E	4749600N
A-055	Mh	DCD	1	NIAGARA	LINCOLN	78-4359-29-360	14	VII	112	Private	30M/3 & 30M/6 NIAGARA	17T 625150E	4775750N
A-057	By, Mh	DCD	1	MAPLE	TOWN OF WHITCHURCH	n/a	22	V	n/a	Public	31D/3 NEWMARKET	17T 632000E	4771500N

APPENDIX 1: Locations of the sugar maple (sampled 1986) and yellow birch (sampled 1987) foliage and soil sampling plots in Ontario.

Plot Number	Foliage Sampling	Forest Region	Forest Sector	MNR District	Township	Air Photo No.	Lot	Conc.	FRI Stand	Ownership	NTS 1:50000 Map Sheet	UTM Coordinates	
A-060	Mh	GLSL	1	LINDSAY	CLARKE	n/a	21	VIII	n/a	Public	31D/2 SCUGOG	17T 691800E	4880750N
A-062	By, Mh	GLSL	4C	BANCROFT	McCLURE	77-4514-53-208	5	XIII	101	Public	31E/8 WHITNEY	17T 733250E	5023650N
A-064	By, Mh	GLSL	4D	MINDEN	GLAMORGEN	77-4440-32-121	18	XIV	112	Public	31D/16 GOODERHAM	17T 700650E	4982200N
A-066	By	GLSL	4D	MINDEN	HINDON	77-4502-34-98	29	X	153	Public	31E/2 HALIBURTON	17T 659800E	4991900N
A-069	Mh	DCO	1	CHATHAM	ZARE	78-4253-250-98	31	VII	n/a	Public	40I/12 BOTHWELL	17T 426150E	4731550N
A-070	Mh	DCO	1	AYLMER	EAST WILLIAMS	78-4312-234-57	3	XX	n/a	Public	40P/4 PARKHILL	17T 447650E	4778650N
A-071	By	GLSL	4D	PARRY SOUND	GEORGIAN BAY	77-4502-34-56	3	VIII	Ind. R	Private	31E/4 LAKE JOSEPH	17T 598550E	4986100N
A-073	Mh	GLSL	1	LINDSAY	ASPHODEL	78-4420-8-368	9	III	n/a	Private	31D/8 PETERBOROUGH	17T 736000E	4911600N
A-077	Mh	GLSL	1	WINGHAM	MORRIS	78-4350-268-127	26	VIII	n/a	Public	40P/11 SEAFORTH	17T 476150E	4839900N
A-079	By, Mh	GLSL	4C	TWEED	ANGLESEA	78-4463-78-24	n/a	n/a	217	Public	31C/14 MAZINAW LAKE	18T 321800E	4974500N
A-083	By, Mh	GLSL	2	NAPANEE	BEDFORD	n/a	n/a	n/a	P.P.Re	Public	31C/10 TICHBORNE	18T 379050E	4936100N
A-087	Mh	GLSL	1	OWEN SOUND	SAUGEEN	n/a	11	IV	n/a	Public	41A/6 CHESLEY	17T 475050E	4911000N
A-089	Mh	GLSL	4D	PARRY SOUND	McKENZIE	77-4530-86-34	29	VII	n/a	Public	41H/9 POINTE AU BARIL STN	17T 574550E	5062650N
A-090	By	GLSL	4D	PARRY SOUND	FERRIE	77-4532-43-142	25	VII	222	Public	31E/13 GOLDEN VALLEY	17T 590850E	5068350N
A-095	Mh	GLSL	4E	ESPANOLA	ROBINSON	73-4537-8-50	28	XI	208	Private	41G/15 SILVER WATER	17T 353300E	5083400N
A-096	By, Mh	GLSL	4B	ALGONQUIN PARK	FINLAKSON	n/a	n/a	n/a	332	Public	31E/7 KAWAGAMA LAKE	17T 670150E	5033900N
A-097	By	GLSL	4B	ALGONQUIN PARK	PECK	n/a	n/a	n/a	272	Public	31E/10 TOM THOMSON LAKE	17T 681400E	5045600N
A-098	By	GLSL	4B	ALGONQUIN PARK	SPROULE	n/a	n/a	n/a	821	Public	31E/9 OPEONGO LAKE	17T 710650E	5051700N
A-099	By	GLSL	4B	ALGONQUIN PARK	DICKSON	n/a	n/a	n/a	n/a	Public	31E/16 LAKE LAVIELLE	17T 707400E	5077300N
A-101	By	GLSL	4E	NORTH BAY	NIPISSING	77-4604-81-122	n/a	n/a	n/a	Public	31L/4 NIPISSING	17T 610700E	5105550N
A-104	By	GLSL	4E	NORTH BAY	PAPINEAK	77-4608-69-146	22	XII	n/a	Private	31L/7 MATTAWA	17T 673500E	5127500N
A-108	Mh	GLSL	11	THUNDER BAY	BLAKE	n/a	n/a	n/a	n/a	Public	52A/6 THUNDER BAY	16U 322650E	5349500N
A-110	Mh	GLSL	11	THUNDER BAY	PARDEE	n/a	n/a	n/a	n/a	Public	52A/4 PIDGEON RIVER	16U 307400E	5326300N

APPENDIX 2

Listing of soil and decline index data for each plot.

APPENDIX 2: Field descriptions of the soil pits sampled at each sugar maple and yellow birch foliage sampling plot, 1986-1987.

Plot	Foliage Sampling	Forest Region	Forest Sector	OMNR District	Depths (cm) to: Bedrock	Free Carb.	Drainage	Moisture Regime	Layer 1: (A Horizon) Texture	Thickness	Layer 2: (B Horizon) Texture	Thickness	Layer 3: Texture	Position On Slope
A-002	By, Mh	GL	4B	BRACEBRIDGE	80	199	well	2	SL	10	SL	30	SL	upper
A-003	By	GL	4B	NORTH BAY	199	199	well	2	L	8	L	39	L	upper
A-004	By, Mh	GL	4B	NORTH BAY	51	199	well	2	S	11	SL	27	SL	upper
A-005	By	GL	4B	BRACEBRIDGE	35	199	well	2	L	13	L	22	N/A	upper
A-006	By	GL	2	CORNWALL	65	199	well	2	fSL	7	fSL	23	fSL	upper
A-008	By, Mh	GL	2	CORNWALL	30	199	well	2	CL	7	CL	11	CL	flat
A-009	Mh	GL	4B	PEMBROKE	199	199	rapid	1	LfS	1	LS	9	fS	flat
A-011	Mh	GL	2	CARLETON PL	199	199	well	2	SL	9	SL	9	SL	crest
A-012	Mh	GL	2	BROCKVILLE	53	199	rapid	1	LfS	10	LfS	10	LfS	middle
A-013	By, Mh	GL	10	SAULTSTMARIE	199	199	rapid	1	LS	5	LS	25	LS	flat
A-014	Mh	GL	2	CORNWALL	55	199	well	2	SL	8	SL	35	SL	flat
A-015	By	GL	10	WAWA	30	199	well	2	CL	6	L	24	N/A	crest
A-017	Mh	GL	40	PARRY SOUND	55	199	well	2	fSL	14	fSL	27	fSL	upper
A-018	By	GL	40	PARRY SOUND	55	199	well	2	fSL	13	fSL	25	fSL	flat
A-020	By, Mh	GL	1	HURONIA	35	199	well	2	fSL	15	L	10	L	middle
A-021	By	GL	4B	HURONIA	40	199	well	2	L	9	L	15	L	middle
A-023	By	GL	4B	HURONIA	199	199	well	2	mS	4	N/A	12	N/A	flat
A-024	By, Mh	GL	4B	HURONIA	60	199	well	2	mS	15	mS	45	N/A	lower
A-027	By, Mh	GL	1	SUDBURY	199	199	well	2	Si	5	Si	40	Si	flat
A-030	Mh	GL	4E	ESPANOLA	199	199	mod.well	3	SiL	4	SifS	26	CL	lower
A-033	By, Mh	GL	10	BLIND RIVER	20	199	rapid	1	LmS	6	LfS	14	N/A	middle
A-035	By	GL	10	BLIND RIVER	70	199	well	2	vfSL	5	vfSL	45	L	upper
A-037	By	GL	10	SAULTSTMARIE	50	199	rapid	1	fLS	6	LfS	21	fLS	crest
A-039	By	GL	10	SAULTSTMARIE	40	199	well	2	vfSL	10	L	30	N/A	middle
A-040	By	GL	10	SAULTSTMARIE	70	199	mod.well	3	fSL	6	fSL	35	LS	flat
A-043	Mh	DC	1	NIAGARA	199	0	well	2	GL	8	GL	32	N/A	flat
A-045	Mh	DC	1	CAMBRIDGE	199	199	well	2	L	20	CL	40	N/A	middle
A-046	By	DC	1	SIMCOE	199	80	mod.well	3	L	30	SiL	50	SiL	flat
A-047	By, Mh	DC	1	AYLMER	199	199	well	2	fSL	20	fSL	80	fSL	N/A
A-048	Mh	DC	1	SIMCOE	199	199	imperfect	5	SiL	25	SivfS	42	N/A	middle
A-055	Mh	DC	1	NIAGARA	199	75	well	2	SiL	20	SiCL	55	SiCL	flat
A-057	By, Mh	DC	1	MAPLE	199	199	well	2	SifS	5	vfSL	12	vfSL	middle

APPENDIX 2: Field descriptions of the soil pits sampled at each sugar maple and yellow birch foliage sampling plot, 1986-1987.

Plot	Foliage Sampling	Forest Region	Forest Sector	OMNR District	Depths (cm) to: Bedrock	Free Carb.	Drainage	Moisture Regime	Layer 1: (A Horizon) Texture	Thickness	Layer 2: (B Horizon) Texture	Thickness	Layer 3: Texture	Position On Slope
A-060	Mh	GL	1	LINDSAY	199	20	well	2	vfSL	20	fSL	25	fS	middle
A-062	By, Mh	GL	4C	BANCROFT	60	199	rapid	0	LS	8	LfS	50	N/A	middle
A-064	By, Mh	GL	4D	MINDEN	90	199	mod.well	3	LvfS	15	SivfS	40	SifS	upper
A-066	By	GL	4D	MINDEN	60	199	well	2	LvfS	20	LvfS	40	N/A	upper
A-069	Mh	DC	1	CHATHAM	199	85	well	2	LvfS	10	LvfS	90	N/A	flat
A-070	Mh	DC	1	AYLMER	199	45	rapid	0	LmS	15	LmS	40	Lms	crest
A-071	By	GL	4D	PARRY SOUND	199	42	mod.well	4	vfS	6	vfS	42	N/A	middle
A-073	Mh	GL	1	LINDSAY	199	199	well	2	vfSL	20	LvfS	40	LvfS	N/A
A-077	Mh	GL	1	WINGHAM	199	25	N/A	2	L	8	vfSL	20	fS	lower
A-079	By, Mh	GL	4C	TWEED	70	199	well	2	vfSL	8	vfSL	15	vfSL	upper
A-083	By, Mh	GL	2	NAPANEE	70	199	mod.well	2	CL	8	SiC	52	N/A	middle
A-087	Mh	GL	1	OWEN SOUND	199	199	mod.well	3	fSL	18	vfS	58	vfS	N/A
A-089	Mh	GL	4D	PARRY SOUND	70	199	well	2	SiL	10	SiL	30	SiL	middle
A-090	By	GL	4D	PARRY SOUND	199	199	imperfect	4	SiL	11	SifS	29	fSL	N/A
A-095	Mh	GL	4E	ESPANOLA	50	199	well	1	vfS	15	SifS	30	N/A	N/A
A-096	By, Mh	GL	4B	ALGONQUINPK	199	199	well	2	L	10	LvfS	50	LfS	middle
A-097	By	GL	4B	ALGONQUINPK	100	199	well	2	L	15	vfSL	45	LfS	middle
A-098	By	GL	4B	ALGONQUINPK	199	199	well	2	fSL	10	fSL	28	LvfS	upper
A-099	By	GL	4B	ALGONQUINPK	70	199	N/A	2	vfSL	15	SivfS	35	SivfS	crest
A-101	By	GL	4E	NORTH BAY	80	199	well	2	L	8	SiL	47	LmS	upper
A-104	By	GL	4E	NORTH BAY	60	199	mod.well	3	vfSL	5	L	30	vfSL	middle
A-108	Mh	GL	11	THUNDER BAY	199	199	mod.well	4	L	10	L	40	L	middle
A-110	Mh	GL	11	THUNDER BAY	199	199	imperfect	5	fSL	10	SCL	40	N/A	middle

APPENDIX 2: Mean height, diameter at breast height (DBH) and mean decline index for the yellow birch trees sampled adjacent to the hardwood decline plots in 1987.

PLOT NUMBER	OMNR DISTRICT	MEAN HEIGHT (m)	MEAN DBH (cm)	MEAN DECLINE INDEX (5 trees, 1987)
2	BRACEBRIDGE	16	12.0	8.6
3	NORTH BAY	25	30.0	18.0
4	NORTH BAY	27	19.0	40.0
5	BRACEBRIDGE	21	22.0	6.8
6	CORNWALL	17	16.3	7.4
8	CORNWALL	16	19.0	1.3
13	SAULT STE. MARIE	17	21.5	43.8
15	WAWA	6	20.0	2.5
18	PARRY SOUND	24	35.6	3.1
20	HURONIA	17	21.0	7.5
21	HURONIA	21	35.0	6.3
23	HURONIA	17	22.7	21.9
24	HURONIA	17	15.0	1.9
27	SUDBURY	20	21.7	8.1
33	BLIND RIVER	23	28.3	3.1
35	BLIND RIVER	20	26.3	3.1
37	SAULT STE. MARIE	21	14.0	47.5
39	SAULT STE. MARIE	17	11.0	2.5
40	SAULT STE. MARIE	25	35.2	5.0
46	SIMCOE	16	16.0	1.3
47	AYLMER	25	30.0	1.3
57	MAPLE	19	16.0	1.3
62	BANCROFT	26	44.0	7.5
64	MINDEN	24	33.0	1.3
66	MINDEN	21	23.6	32.5
71	PARRY SOUND	19	13.6	1.3
79	TWEED	10	12.0	2.5
83	NAPANEE	22	36.0	15.0
90	PARRY SOUND	25	21.5	8.0
96	ALGONQUIN PARK	31	44.0	21.3
97	ALGONQUIN PARK	19	24.8	44.5
98	ALGONQUIN PARK	19	17.2	0.0
99	ALGONQUIN PARK	9	12.0	3.8
101	NORTH BAY	15	13.2	2.5
104	NORTH BAY	25	33.4	7.4

3. Plots were sampled between 08/25 and 09/13/1987.

APPENDIX 2: Mean age, diameter at breast height (DBH) and mean decline index for sugar maples, for the plots sampled for sugar maple foliage in 1986.

PLOT NUMBER	OMNR DISTRICT	MEAN DBH (cm)	MEAN AGE	DECLINE INDEX (1986)
A-002	BRACEBRIDGE	21.0	93	11.0
A-004	NORTHBAY	21.8	n/a	11.0
A-008	CORNWALL	22.6	73	10.4
A-009	PEMBROKE	22.3	77	14.7
A-011	CARLETONPL	20.8	n/a	15.3
A-012	BROCKVILLE	22.6	93	6.6
A-013	SAULTSTMARIE	22.4	78	19.9
A-014	CORNWALL	22.0	81	11.2
A-017	PARRYSOUND	17.7	76	24.6
A-020	HURONIA	26.8	85	13.2
A-024	HURONIA	25.0	95	10.9
A-027	SUDBURY	23.2	117	9.1
A-030	ESPANOLA	26.3	127	16.8
A-033	BLINDRIVER	24.4	n/a	11.5
A-043	NIAGARA	29.2	60	15.1
A-045	CAMBRIDGE	26.4	77	16.8
A-047	AYLMER	30.2	65	15.0
A-048	SIMCOE	27.5	96	8.8
A-055	NIAGARA	23.4	60	16.2
A-057	MAPLE	26.8	89	5.4
A-060	LINDSAY	24.9	76	3.7
A-062	BANCROFT	21.3	67	7.1
A-064	MINDEN	28.0	n/a	17.1
A-069	CHATHAM	57.7	60	12.3
A-070	AYLMER	26.4	81	10.9
A-073	LINDSAY	30.6	96	10.4
A-077	WINGHAM	19.8	75	9.9
A-079	TWEED	24.9	97	10.7
A-083	NAPANEE	22.5	85	7.5
A-087	OWENSOUND	35.4	77	13.3
A-089	PARRYSOUND	19.2	74	15.3
A-095	ESPANOLA	26.2	122	18.3
A-096	ALGONQUINPK	30.4	93	17.2
A-108	THUNDERBAY	20.7	78	13.4
A-110	THUNDERBAY	19.2	n/a	13.8

APPENDIX 3

MOE soil and foliar chemical analyses: procedures and measurement units.

SOIL CHEMISTRY - MOE LABORATORY TECHNIQUES AND ORIGINAL MEASUREMENT UNITS

VARIABLE	LAB TECHNIQUE	UNITS
SAND	% SAND, PARTICLE SIZE	% DRY WEIGHT
SILT	% SILT PARTICLE SIZE	% DRY WEIGHT
CLAY	% CLAY PARTICLE SIZE	% DRY WEIGHT
ORGC	% ORGANIC CARBON	% ORGANIC CARBON
CEC	CATION EXCHANGE CAPACITY	MEQ/100g
TIC	TOTAL INORGANIC CARBON	% DRY WT AS CARBON
PHEW	PH, WATER EXTRACTABLE	DIMENSIONLESS
PHECA	PH, CALCIUM CHLORIDE EXTRACT	DIMENSIONLESS
MACRONUTRIENTS		
NNTKUR	NITROGEN, TOTAL KJELDAHL, UNF.R.	MG/G DRY AS N
KKESC	POTASSIUM, SOD.CHLORID EXTRACT	MEQ/100g
CAESC	CALCIUM, SOD.CHLORIDE EXTRACT	MEQ/100g
MGESC	MAGNESIUM, SOD.CHLORID EXTRACT	MEQ/100g
SS04EW	SULFATE, EXT. IN WATER	UG/G DRY AS SO4
MICRONUTRIENTS		
CUUT	COPPER, UNF.TOTAL	UG/G DRY AS Cu
FEEPY	IRON, PYROPHOSPHATE EXTRACT	% DRY WT AS Fe
FEEDI	IRON, DITHIONITE EXTRACT	% DRY WT AS Fe
ZNUT	ZINC, UNF.TOTAL	UG/G DRY AS Zn
OTHER ELEMENTS		
ALESC	ALUMINIUM, SODIUM CHLORIDE EXTRACT	MEQ/100g
ALECA	ALUMINIUM, EXTRACT IN CaCL2	UG/G DRY WT AS Al
ALEPY	ALUMINIUM, PYROPHOSHATE EXTRACT	% DRY WT AS Al
ALEDI	ALUMINIUM, DITHIONITE EXTRACT	% DRY WT AS Al
NIUT	NICKEL, UNF.TOTAL	UG/G DRY AS Ni
PBUT	LEAD, UNF.TOTAL	UG/G DRY AS Pb

FOLIAR CHEMISTRY - MOE LABORATORY TECHNIQUES AND ORIGINAL MEASUREMENT UNITS

VARIABLE	LAB TECHNIQUE	UNITS
MACRONUTRIENTS		
NNTKUR	NITROGEN, TOTAL KJELDAHL	MG/G DRY AS N
PPUT	PHOSPHORUS, UNF. TOTAL	MG/G DRY AS P
KKUT	POTASSIUM, UNF. TOTAL	% DRY WT AS K
CAUT	CALCIUM, UNF. TOTAL	UG/G DRY AS Ca
MGUT	MAGNESIUM, UNF. TOTAL	UG/G DRY AS Mg
SSUT	SULPHUR, UNF. TOTAL	% DRY WT AS Sulphur
MICRONUTRIENTS		
CUUT	COPPER, UNF. TOTAL	UG/G DRY AS Cu
FEUT	IRON, UNF. TOTAL	UG/G DRY AS Fe
MNUT	MANGANESE, UNF. TOTAL	UG/G DRY AS Mn
NAUT	SODIUM, UNF. TOTAL	UG/G DRY AS Na
ZNUT	ZINC, UNF.TOTAL	UG/G DRY AS Zn
OTHER ELEMENTS		
ALUT	ALUMINUM, UNF. TOTAL	UG/G DRY AS Al
CDUT	CADMIUM, UNF. TOTAL	UG/G DRY AS Cd
CLUT	CHLORINE, UNF. TOTAL	% DRY WT AS Cl
MOUT	MOLYBDENUM, UNF. TOTAL	UG/G DRY AS Mo
NIUT	NICKEL, UNF.TOTAL	UG/G DRY AS Ni
PBUT	LEAD, UNF. TOTAL	UG/G DRY AS Pb

APPENDIX 4

Mean sugar maple and yellow birch foliage chemistry by wet SO4 loading zones; mean soil 'A' and 'B' horizon chemistry; mean chemistry for the soil cores conducted in conjunction with the yellow birch foliage sampling; and plot mean decline indices by wet SO4 loading zones.

Mean sugar maple foliage chemistry and plot mean decline indices by wet SO4 deposition zones.

FOLIAGE ELEMENT		SO4 DEPOSITION (KG/HA/YR) >35	30–35	25–30	20–25	15–20	<10
MACRONUTRIENTS							
N	(%)	2.27	2.02	1.86	1.79	2.50	2.01
P	(%)	0.15	0.18	0.15	0.19	0.14	0.24
K	(%)	0.84	0.78	0.83	0.82	0.77	1.28
Ca	(%)	1.49	1.48	1.25	1.12	1.18	1.13
Mg	(%)	0.19	0.21	0.17	0.18	0.15	0.21
S	(%)	0.21	0.20	0.19	0.18	0.20	0.23
MICRONUTRIENTS							
Cu	(ppm)	4.75	5.18	5.45	5.40	6.20	7.17
Fe	(ppm)	146	93	66	74	59	54
Mn	(ppm)	380	561	921	842	2280	594
Na	(ppm)	12.45	11.83	11.20	11.08	10.00	14.63
Zn	(ppm)	17.05	22.89	22.70	24.04	38.80	27.00
OTHER ELEMENTS							
Al	(ppm)	95	53	35	39	34	23
Cd	(ppm)	0.22	0.27	0.30	0.29	0.40	0.33
Cl	(%)	0.07	0.08	0.05	0.04	0.05	0.02
Mo	(ppm)	0.54	0.55	0.52	0.51	0.50	0.50
Ni	(ppm)	1.05	1.65	1.88	1.76	2.40	2.00
Pb	(ppm)	1.60	1.56	1.61	1.24	2.60	1.29
DECLINE INDEX		11.74	12.40	11.79	14.47	19.89	13.58

Mean soil 'A' horizon chemistry by wet SO4 deposition zones.

SOIL ATTRIBUTE		SO4 DEPOSITION (KG/HA/YR) >35	30–35	25–30	20–25	15–20	<10
Depth to bedrock (cm)		200.00	163.18	94.42	104.20	200.00	200.00
Moisture regime		2.25	2.18	1.75	1.60	1.00	4.50
Horizon thickness (cm)		17.50	14.46	9.33	7.40	5.00	10.00
% SILT		18.25	36.36	29.17	37.60	43.00	53.00
% CLAY		12.50	12.91	12.50	8.00	11.00	14.00
% SAND		69.00	50.91	58.50	54.40	47.00	33.00
% Organic Carbon		2.78	4.14	5.57	3.04	3.40	2.40
Cation Exchange Capacity	(meq/100g)	9.27	11.92	10.11	10.55	5.75	10.87
pH (water)		6.38	5.68	5.39	5.20	4.00	5.25
pH (CaCl2 buffered)		5.95	5.30	4.93	4.78	3.70	4.70
MACRONUTRIENTS							
N	(%)	2.30	3.32	4.49	2.50	2.80	0.40
K	(meq/100g)	0.09	0.15	0.16	0.10	0.09	0.18
Ca	(meq/100g)	8.08	9.53	7.94	7.03	3.62	8.60
Mg	(meq/100g)	1.02	1.53	0.97	2.36	0.42	1.97
SO4	(ppm)	36.53	64.29	48.25	30.00	40.00	16.50
MICRONUTRIENTS							
Fe (EPY)	(%)	0.19	0.38	0.76	0.37	0.47	0.37
Fe (EDI)	(%)	0.96	1.16	1.42	0.95	0.98	1.57
Cu	(ppm)	11.90	14.66	12.38	9.22	11.00	34.00
Zn	(ppm)	67.25	75.09	63.58	57.40	48.00	152.00
OTHER ELEMENTS							
Al (ESC)	(meq/100g)	0.09	0.72	1.04	1.06	1.62	0.12
Al (ECA)	(ppm)	2.75	11.44	10.33	9.36	19.60	1.55
Al (EPY)	(%)	0.13	0.31	0.37	0.20	0.17	0.18
Al (EDI)	(%)	0.19	0.39	0.44	0.23	0.14	0.23
Ni	(ppm)	12.95	16.14	13.72	12.14	6.30	40.00
Pb	(ppm)	29.50	32.98	21.08	16.48	12.00	14.00

Mean soil 'B' horizon chemistry by wet SO4 deposition zones.

ZONE		SO4 DEPOSITION (KG/HA/YR) >35	30–35	25–30	20–25	15–20	<10
Depth to bedrock (cm)		200.00	163.18	94.42	104.20	200.00	200.00
Moisture regime		2.25	2.18	1.75	1.60	1.00	4.50
Horizon thickness (cm)		63.00	32.91	31.17	21.20	25.00	40.00
% SILT		14.50	34.55	29.17	32.80	38.00	44.50
% CLAY		9.75	13.55	7.25	5.20	6.00	11.50
% SAND		75.25	51.91	63.58	62.00	55.00	44.00
% Organic Carbon		1.55	2.08	3.17	2.50	4.50	1.30
Cation Exchange Capacity	(meq/100g)	6.04	8.53	5.06	5.82	3.17	5.57
pH (water)		6.45	6.17	5.34	5.70	4.70	5.30
pH (CaCl2 buffered)		5.90	5.68	4.77	5.16	4.20	4.60
MACRONUTRIENTS							
N	(%)	1.30	1.11	2.52	2.60	3.10	1.80
K	(meq/100g)	0.09	0.07	0.08	0.05	0.06	0.10
Ca	(meq/100g)	5.12	6.75	3.07	4.06	0.94	3.84
Mg	(meq/100g)	0.67	1.18	0.59	0.93	0.13	1.18
SO4	(ppm)	23.30	25.29	20.85	16.00	12.00	5.60
MICRONUTRIENTS							
Fe (EPY)	(%)	13.00	18.06	15.62	10.90	10.00	50.00
Fe (EDI)	(%)	0.10	0.27	0.81	0.56	0.95	0.48
Cu	(ppm)	1.05	1.36	1.50	1.19	1.79	1.81
Zn	(ppm)	57.50	72.64	61.17	52.60	93.00	118.50
OTHER ELEMENTS							
Al (ESC)	(meq/100g)	0.16	0.54	1.33	0.78	2.04	0.46
Al (ECA)	(ppm)	1.59	4.56	13.08	9.34	24.40	2.65
Al (EPY)	(%)	0.11	0.21	0.59	0.60	1.09	0.25
Al (EDI)	(%)	0.21	0.33	0.68	0.67	1.29	0.30
Ni	(ppm)	14.30	16.01	17.03	17.80	16.00	54.50
Pb	(ppm)	19.00	24.08	10.78	13.22	12.00	13.50

Mean yellow birch foliage chemistry and plot mean decline indices by wet SO4 deposition zones.

FOLIAGE ELEMENT		SO4 DEPOSITION (KG/HA/YR) >35	30-35	25-30	20-25	15-20	<10
MACRONUTRIENTS							
N	(%)	2.60	2.57	2.59	2.57	2.34	2.39
P	(%)	0.13	0.17	0.17	0.21	0.21	0.18
K	(%)	1.17	1.27	1.10	1.18	0.91	1.14
Ca	(%)	1.11	1.35	1.34	1.60	1.88	1.25
Mg	(%)	0.21	0.31	0.28	0.33	0.25	0.26
S	(%)	0.13	0.15	0.14	0.14	0.13	0.14
MICRONUTRIENTS							
Cu	(ppm)	6.44	6.50	6.30	5.96	6.34	6.65
Fe	(ppm)	87.60	103.04	95.34	93.17	149.30	81.33
Mn	(ppm)	2118.00	1472.00	1730.35	1282.90	1756.00	2620.00
Na	(ppm)	11.60	15.24	13.57	13.43	22.30	13.33
Zn	(ppm)	332.00	361.20	338.24	284.40	288.00	398.67
OTHER ELEMENTS							
Al	(ppm)	61.40	59.24	50.87	49.30	95.50	44.73
Cd	(ppm)	2.84	2.75	2.58	2.00	1.89	2.96
Cl	(%)	0.01	0.01	0.01	0.01	0.03	0.01
Mo	(ppm)	0.37	0.50	0.51	0.46	0.41	0.43
Ni	(ppm)	2.09	2.80	2.65	2.24	2.74	3.55
Pb	(ppm)	1.65	2.32	2.11	2.54	2.65	2.64
Decline Index		8.17	6.46	9.41	5.45	6.93	7.91

Mean soil cores chemistry (conducted in conjunction with the yellow birch foliage sampling) by wet SO4 deposition zones.

SOIL ATTRIBUTE		SO4 DEPOSITION (KG/HA/YR) >35	30-35	25-30	20-25	15-20	<10
% SILT		52.90	28.40	31.55	30.67	27.10	43.00
% CLAY		8.70	7.12	8.30	9.20	6.70	9.40
% SAND		38.60	64.44	60.11	60.13	66.10	47.33
% Organic Carbon		4.06	3.22	4.29	4.31	3.62	6.03
Cation Exchange Capacity	(meq/100g)	4.61	3.20	4.53	9.75	4.63	4.41
pH (water)		4.17	4.72	4.79	5.42	5.30	4.38
pH (CaCl2 buffered)		3.80	4.21	4.29	4.98	4.88	3.96
MACRONUTRIENTS							
N	(%)	2.33	1.72	2.19	2.57	2.04	2.90
K	(meq/100g)	0.12	0.08	0.09	0.10	0.06	0.10
Ca	(meq/100g)	1.29	1.63	2.53	7.31	3.11	1.07
Mg	(meq/100g)	0.25	0.22	0.37	1.30	0.19	0.21
SO4	(ppm)	36.58	28.64	31.81	34.36	23.41	57.56
MICRONUTRIENTS							
Fe (EPY)	(%)	0.89	0.73	0.78	0.76	0.70	0.91
Fe (EDI)	(%)	1.22	1.20	1.25	1.36	0.93	1.29
Cu	(ppm)	7.56	8.08	9.23	12.89	4.85	8.61
Zn	(ppm)	45.10	34.72	42.67	62.43	27.90	32.47
OTHER ELEMENTS							
Al (ESC)	(meq/100g)	2.96	1.26	1.53	1.05	1.28	2.77
Al (ECA)	(ppm)	41.10	17.82	20.40	15.85	19.11	33.53
Al (EPY)	(%)	0.51	0.44	0.59	0.43	0.65	0.87
Al (EDI)	(%)	0.55	0.51	0.65	0.47	0.68	0.92
Ni	(ppm)	10.38	10.07	11.50	13.42	7.25	6.84
Pb	(ppm)	21.70	19.08	22.09	29.99	24.00	17.93

APPENDIX 5

Mean soil and associated foliage chemistry
for the yellow birch and sugar maple sampling
programs, for each OMNR Administrative District.

Mean values for aluminum levels in the soil and in sugar maple foliage samples, by OMNR Administrative Districts.

OMNR DISTRICT	SOIL HORIZON:	SOIL Al (ECA) (ppm) A	B	C	SOIL Al (EDI) (%) A	B	C	SOIL Al (EPY) (%) A	B	C	SOIL Al (ESC) (meq/100g) A	B	C	FOLIAGE Al (ppm)
ALGONQUIN	.	2.3	7.9	3.5	0.24	1.00	0.29	0.22	0.87	0.23	0.12	0.91	0.38	32
AYLMER	.	1.3	0.2	0.4	0.20	0.16	0.15	0.12	0.08	0.05	0.02	0.02	0.04	70
BANCROFT	.	6.9	11.8		0.52	0.76		0.38	0.60		0.65	1.13		29
BLIND RIVER	.	20.8	21.8		0.17	0.90		0.16	0.88		3.65	2.04		29
BRACEBRIDGE	.	14.4	17.5	7.8	0.17	1.04	0.56	0.16	0.98	0.45	0.78	1.36	0.65	30
BROCKVILLE	.	3.8	2.6		0.08	0.42		0.07	0.32		0.11	0.32		27
CAMBRIDGE	.	0.3	0.1		0.35	0.48		0.14	0.10		0.04	0.03		38
CARLETON PLACE	.	3.6	4.9	3.7	0.34	0.66	0.44	0.30	0.53	0.38	0.16	0.42	0.38	38
CHATHAM	.	8.3	5.5	0.3	0.24	0.35	0.07	0.19	0.23	0.01	0.32	0.60	0.02	150
CORNWALL	.	5.6	10.1	2.1	0.30	0.36	0.21	0.27	0.32	0.16	0.21	1.24	0.37	35
ESPANOLA	.	3.7	2.6	4.5	0.28	0.48	0.20	0.29	0.44	0.21	0.24	0.27	0.55	59
HURONIA	.	0.2	3.1	1.5	0.31	0.41	0.34	0.31	0.33	0.25	0.11	0.36	0.28	40
LINDSAY	.	1.3	0.5	0.3	0.24	0.11	0.09	0.15	0.08	0.04	0.04	0.01	0.02	61
MAPLE	.	0.6	0.8		0.17	0.18		0.12	0.12		0.09	0.03		60
MINDEN	.	6.3	5.0		1.14	0.54		0.81	0.36		1.14	0.43		34
NAPANEE	.	0.4	0.3	0.4	0.22	0.27	0.25	0.11	0.06	0.06	0.01	0.01	0.01	20
NIAGARA	.	35.4	17.4	0.4	0.30	0.31	0.17	0.23	0.25	0.04	1.43	2.31	0.01	75
NORTH BAY	.	18.0	17.9	6.8	0.09	1.03	0.26	0.09	0.93	0.21	1.12	1.19	0.44	25
OWEN SOUND	.	16.1	1.0	0.2	0.26	0.27	0.06	0.22	0.22	0.01	1.14	0.03	0.02	73
PARRY SOUND	.	27.7	22.9	17.5	1.30	1.00	0.59	1.22	0.97	0.53	3.32	1.98	1.50	55
PEMBROKE	.	0.7	1.8		0.36	0.47		0.20	0.30		0.07	0.14		22
SAULT STE MARIE	.	19.6	24.4		0.14	1.29		0.17	1.09		1.62	2.04		34
SIMCOE	.	0.1	0.4		0.13	0.17		0.09	0.05		0.01	0.01		88
SUDBURY	.	23.4	37.5	1.3	0.23	0.39	0.06	0.24	0.42	0.07	3.66	3.74	0.43	28
THUNDER BAY	.	1.6	2.7	0.1	0.23	0.30	0.11	0.18	0.25	0.08	0.12	0.46	0.01	23
TWEED	.	26.2	13.2		0.71	0.56		0.54	0.40		1.97	1.20		29
WINGHAM	.	0.4	0.1	0.6	0.18	0.27	0.07	0.13	0.09	0.01	0.01	0.01	0.01	38

NOTES: ECA = CaCl2 extract; EDI = dithionite extract; EPY = pyrophosphate extract; ESC = NaCl extract.

Mean values for soil pH, % organic carbon and cation exchange capacity for sites associated with sugar maple foliage sampling, by OMNR Districts.

OMNR DISTRICT	SOIL HORIZON:	pH (CaCl2)			pH (water)			% Organic Carbon			Cation Exchange Capacity (meq/100g)		
		A	B	C	A	B	C	A	B	C	A	B	C
ALGONQUIN	.	5.3	4.5	4.7	5.8	5.1	5.2	6.0	3.5	0.8	12.4	1.7	0.6
AYLMER	.	6.4	6.3	7.3	6.9	6.9	7.9	2.3	2.5	0.7	6.9	8.3	5.1
BANCROFT	.	4.5	4.4		5.0	4.9		7.7	3.5		7.6	2.3	
BLIND RIVER	.	3.5	4.2		4.0	4.7		3.1	3.8		5.7	3.5	
BRACEBRIDGE	.	4.0	4.4	4.6	4.4	4.8	5.1	3.3	4.2	1.6	4.7	3.2	1.1
BROCKVILLE	.	5.1	4.9		5.7	5.6		3.6	1.4		6.9	2.2	
CAMBRIDGE	.	6.3	6.1		6.6	6.5		3.9	1.3		16.8	12.6	
CARLETON PLACE	.	5.3	4.8	4.8	5.8	5.5	5.5	5.6	2.7	1.5	13.5	4.7	2.9
CHATHAM	.	4.5	4.6	7.6	4.9	4.9	8.4	4.0	0.9	2.8	10.1	0.9	3.6
CORNWALL	.	5.1	5.6	6.2	5.5	6.1	6.7	4.8	2.1	1.0	12.7	9.4	8.6
ESPANOLA	.	5.8	6.1	4.6	6.1	6.6	5.4	3.9	1.9	0.6	20.0	10.0	1.7
HURONIA	.	6.9	6.0	5.0	7.3	6.7	5.7	5.2	2.6	0.9	21.3	8.8	0.8
LINDSAY	.	5.9	6.5	6.9	6.5	7.2	7.9	0.8	0.4	0.4	5.8	3.6	5.9
MAPLE	.	6.2	6.3		6.5	6.7		7.8	1.7		29.5	10.8	
MINDEN	.	4.5	4.6		5.0	5.1		3.1	1.3		1.8	1.0	
NAPANEE	.	6.2	6.2	6.2	6.6	6.7	6.8	5.4	1.1	1.0	16.1	14.0	14.0
NIAGARA	.	3.9	4.2	7.4	4.1	4.6	7.8	5.8	1.7	0.4	9.6	4.4	12.7
NORTH BAY	.	3.6	4.3	4.5	3.9	4.9	5.0	3.3	3.5	0.8	3.5	1.8	0.6
OWEN SOUND	.	4.0	5.3	7.5	4.4	6.0	8.1	3.9	0.8	0.1	8.2	3.1	3.1
PARRY SOUND	.	4.3	4.4	4.2	4.9	4.9	4.7	9.6	10.0	2.0	4.9	10.6	1.8
PEMBROKE	.	5.3	5.1		5.9	5.7		1.0	1.5		3.6	3.8	
SAULT STE MARIE	.	3.7	4.2		4.0	4.7		3.4	4.5		5.8	3.2	
SIMCOE	.	6.6	6.4		6.8	7.1		2.6	0.3		13.1	6.6	
SUDBURY	.	3.7	4.0	4.2	4.2	4.5	5.3	2.7	1.4	0.2	6.6	4.8	4.1
THUNDER BAY	.	4.7	4.6	5.3	5.3	5.3	6.3	2.4	1.3	0.5	10.9	5.6	6.8
TWEED	.	4.2	4.3		4.5	4.7		3.3	2.2		2.7	1.8	
WINGHAM	.	6.3	6.8	7.6	6.6	7.3	8.4	3.6	1.0	5.9	16.7	18.3	3.8

Mean values for calcium and magnesium levels in the soil and in sugar maple foliage samples, by OMNR Administrative Districts.

OMNR DISTRICT	SOIL HORIZON:	SOIL Ca (meq/100g) A	B	C	FOLIAGE Ca (%)	SOIL Mg (meq/100g) A	B	C	FOLIAGE Mg (%)
ALGONQUIN	.	11.3	0.7	0.2	1.062	0.80	0.05	0.01	0.142
AYLMER	.	6.2	7.4	4.7	1.470	0.66	0.76	0.34	0.182
BANCROFT	.	6.9	0.9		1.180	0.03	0.16		0.154
BLIND RIVER	.	1.5	1.2		0.798	0.37	0.19		0.109
BRACEBRIDGE	.	3.4	1.6	0.4	1.400	0.44	0.14	0.05	0.184
BROCKVILLE	.	5.6	1.6		1.180	1.18	0.26		0.216
CAMBRIDGE	.	11.8	7.9		1.680	4.77	4.53		0.238
CARLETON PLACE	.	11.9	3.8	2.2	1.218	1.30	0.50	0.27	0.116
CHATHAM	.	8.6	0.3	3.4	1.486	1.11	0.06	0.10	0.202
CORNWALL	.	10.9	7.2	7.3	1.590	1.42	0.83	0.82	0.213
ESPANOLA	.	14.2	7.7	0.9	1.270	5.40	2.04	0.17	0.259
HURONIA	.	19.1	7.7	0.5	1.700	1.91	0.69	0.05	0.227
LINDSAY	.	5.5	3.5	5.0	1.710	0.19	0.11	0.68	0.184
MAPLE	.	26.8	10.1		1.760	2.31	0.61		0.202
MINDEN	.	0.6	0.4		0.972	0.07	0.15		0.138
NAPANEE	.	12.9	10.2	10.1	1.360	2.83	3.53	3.63	0.242
NIAGARA	.	6.8	1.6	11.6	1.433	1.07	0.43	0.96	0.251
NORTH BAY	.	2.1	0.6	0.1	0.716	0.23	0.03	0.01	0.136
OWEN SOUND	.	6.1	2.6	2.8	1.640	0.83	0.45	0.27	0.228
PARRY SOUND	.	1.1	8.1	0.3	0.860	0.29	0.34	0.03	0.120
PEMBROKE	.	3.1	3.3		1.560	0.39	0.34		0.154
SAULT STE MARIE	.	3.6	0.9		1.178	0.42	0.13		0.150
SIMCOE	.	11.4	5.4		1.520	1.65	1.11		0.184
SUDBURY	.	1.9	0.7	1.6	0.913	0.78	0.25	1.99	0.123
THUNDER BAY	.	8.6	3.8	4.5	1.133	1.97	1.18	2.22	0.213
TWEED	.	0.6	0.4		1.044	0.11	0.06		0.166
WINGHAM	.	13.3	13.5	3.5	1.320	3.28	4.65	0.28	0.262

Mean values for nitrogen and potassium levels in the soil and in sugar maple foliage samples, and for phosphorus levels in sugar maple foliage (soil levels not available) by OMNR Administrative Districts.

OMNR DISTRICT	SOIL HORIZON:	SOIL N (%) A	B	C	FOLIAGE N (%)	SOIL K (%) A	B	C	FOLIAGE K (%)	FOLIAGE P (%)
ALGONQUIN	.	2.3	4.2	2.2	2.40	0.13	0.03	0.03	0.93	0.152
AYLMER	.	2.3	2.2	0.7	2.33	0.08	0.12	0.07	0.88	0.154
BANCROFT	.	8.4	2.6		1.98	0.02	0.07		0.85	0.132
BLIND RIVER	.	2.3	2.2		1.77	0.12	0.07		0.97	0.135
BRACEBRIDGE	.	3.2	3.1	1.5	2.43	0.10	0.03	0.02	0.87	0.153
BROCKVILLE	.	2.5	0.8		1.60	0.06	0.01		0.68	0.108
CAMBRIDGE	.	3.6	1.4		2.08	0.21	0.10		0.72	0.130
CARLETON PLACE	.	5.5	2.1	1.3	1.45	0.17	0.04	0.02	0.89	0.227
CHATHAM	.	2.4	0.6	0.2	2.06	0.11	0.02	0.03	0.78	0.127
CORNWALL	.	4.1	1.9	0.9	1.69	0.16	0.06	0.06	0.77	0.149
ESPANOLA	.	3.8	3.9	0.5	1.74	0.14	0.05	0.04	0.72	0.196
HURONIA	.	4.5	1.9	0.6	1.69	0.11	0.06	0.01	0.68	0.129
LINDSAY	.	0.6	0.4	0.3	2.14	0.03	0.03	0.21	0.76	0.203
MAPLE	.	6.5	1.6		1.80	0.27	0.06		0.75	0.229
MINDEN	.	1.9	0.6		2.15	0.02	0.01		0.84	0.156
NAPANEE	.	4.3	1.0	0.8	1.79	0.43	0.28	0.22	0.76	0.146
NIAGARA	.	5.0	1.4	0.5	1.99	0.34	0.07	0.11	0.82	0.263
NORTH BAY	.	1.9	2.0	0.6	2.30	0.09	0.03	0.02	0.95	0.160
OWEN SOUND	.	3.1	0.6	0.2	19.50	0.13	0.03	0.02	0.78	0.126
PARRY SOUND	.	6.4	4.5	1.0	1.68	0.18	0.14	0.03	0.70	0.110
PEMBROKE	.	0.8	1.0		1.42	0.03	0.04		0.75	0.274
SAULT STE MARIE	.	2.8	3.1		2.50	0.09	0.06		0.77	0.141
SIMCOE	.	2.2	0.3		2.38	0.08	0.09		0.82	0.147
SUDBURY	.	2.2	1.0	0.3	2.09	0.20	0.09	0.06	0.99	0.254
THUNDER BAY	.	0.4	1.8	0.9	1.99	0.18	0.10	0.06	1.27	0.245
TWEED	.	2.2	1.4		2.09	0.08	0.09		1.06	0.168
WINGHAM	.	3.4	1.0	0.3	2.39	0.13	0.16	0.04	0.86	0.167

Mean values for nickel and lead levels in the soil and in sugar maple foliage samples, and for cadmium levels in sugar maple foliage (soil levels not available) by OMNR Administrative Districts.

OMNR DISTRICT	SOIL HORIZON:	SOIL Ni (ppm) A	B	C	FOLIAGE Ni (ppm)	SOIL Pb (ppm) A	B	C	FOLIAGE Pb (ppm)	FOLIAGE Cd (ppm)
ALGONQUIN	.	8.7	14.0	12.0	3.0	18.0	7.5	4.1	2.0	0.46
AYLMER	.	16.4	15.6	19.5	1.0	34.5	25.0	24.5	5.7	0.22
BANCROFT	.	11.0	11.0		1.4	37.0	13.0		1.8	0.18
BLIND RIVER	.	5.3	20.0		2.0	14.0	14.0		1.0	0.30
BRACEBRIDGE	.	6.4	10.0	11.0	2.0	15.0	7.3	4.0	1.2	0.44
BROCKVILLE	.	4.5	4.9		1.0	14.0	1.5		1.4	0.16
CAMBRIDGE	.	20.0	32.0		1.0	83.0	90.0		1.6	0.34
CARLETON PLACE	.	15.0	19.0	22.0	1.2	26.0	9.9	7.8	2.8	0.30
CHATHAM	.	8.0	11.0	11.0	1.2	24.0	12.0	18.0	2.0	0.20
CORNWALL	.	18.5	20.5	24.0	1.0	15.5	12.5	9.7	1.3	0.18
ESPANOLA	.	12.7	19.0	17.0	1.6	20.5	20.0	9.5	1.5	0.22
HURONIA	.	10.5	14.3	6.8	1.1	23.5	18.3	3.8	1.1	0.26
LINDSAY	.	8.1	9.3	11.3	1.1	8.9	10.6	12.5	1.3	0.32
MAPLE	.	8.3	7.1		1.0	39.0	10.0		1.4	0.12
MINDEN	.	10.7	9.4		1.6	9.3	7.2		1.4	0.32
NAPANEE	.	27.0	49.0	44.0	1.0	31.0	21.0	20.0	1.4	0.14
NIAGARA	.	45.5	16.5	30.0	3.0	64.5	22.5	19.0	2.5	0.30
NORTH BAY	.	9.1	11.0	9.1	2.6	21.0	4.8	1.9	1.2	0.46
OWEN SOUND	.	6.8	11.0	9.3	1.0	12.0	8.3	18.0	1.4	0.20
PARRY SOUND	.	11.0	10.2	12.0	1.8	19.0	23.5	7.8	1.6	0.34
PEMBROKE	.	21.0	20.0		1.0	6.4	7.3		1.0	0.24
SAULT STE MARIE	.	6.3	16.0		2.4	12.0	12.0		2.6	0.40
SIMCOE	.	11.0	15.0		1.0	25.0	14.0		2.2	0.22
SUDBURY	.	19.0	22.0	15.0	6.0	17.0	8.1	3.8	1.8	0.48
THUNDER BAY	.	40.0	54.5	42.0	2.0	14.0	13.5	16.0	1.3	0.33
TWEED	.	16.0	14.0		2.0	26.0	8.4		1.4	0.38
WINGHAM	.	2.9	33.0	9.6	1.0	26.0	25.0	12.0	1.4	0.20

Mean values for aluminum levels in the soil and in yellow birch foliage samples, by OMNR Administrative Districts.

OMNR DISTRICT	SOIL AL (ECA) (ppm) A	B	C	SOIL AL (EDI) (%) A	B	C	SOIL AL (EPY) (%) A	B	C	SOIL AL (ESC) (meq/100g) A	B	C	FOLIAGE AL (ppm)
ALGONQUIN	14.7	20.6	14.8	0.19	1.31	0.85	0.17	1.10	0.67	0.96	1.69	1.09	31
AYLMER	2.2	0.2	0.6	0.21	0.12	0.21	0.16	0.06	0.08	0.01	0.03	0.07	117
BANCROFT	6.9	11.8		0.52	0.76		0.38	0.60		0.65	1.13		45
BLIND RIVER	18.9	24.9		0.13	1.16		0.12	1.05		2.54	2.31		45
BRACEBRIDGE	16.8	23.8	7.8	0.15	1.30	0.56	0.14	1.37	0.45	1.48	2.28	0.65	46
CORNWALL	11.1	18.2	4.8	0.21	0.65	0.21	0.19	0.60	0.18	0.45	1.70	0.22	64
HURONIA	2.4	1.5	1.5	0.26	0.36	0.34	0.25	0.29	0.25	0.11	0.14	0.28	58
MAPLE	0.6	0.8		0.17	0.18		0.12	0.12		0.09	0.03		144
MINDEN	10.7	17.3	20.0	0.69	0.94	1.37	0.51	0.82	1.19	1.14	1.48	1.69	44
NAPANEE	0.4	0.3	0.4	0.22	0.27	0.25	0.11	0.06	0.06	0.01	0.01	0.01	47
NORTH BAY	32.0	28.6	10.7	0.15	1.14	0.57	0.14	1.05	0.49	1.58	2.10	0.75	43
PARRY SOUND	14.7	15.7	7.9	0.50	1.24	0.60	0.47	1.08	0.58	1.07	1.42	0.41	62
SAULT STE MARIE	30.7	25.2	15.5	0.29	1.40	0.98	0.29	1.28	0.85	2.43	2.04	1.12	57
SIMCOE	0.4	0.6	0.7	0.20	0.16	0.20	0.14	0.10	0.06	0.01	0.01	0.01	108
SUDBURY	23.4	37.5	1.3	0.23	0.39	0.06	0.24	0.42	0.07	3.66	3.74	0.43	108
TWEED	26.2	13.2		0.71	0.56		0.54	0.40		1.97	1.20		29
WAWA	31.5	31.5		0.09	1.57		0.11	1.52		3.42	5.14		36

NOTES: ECA = CaCl2 extract; EDI = dithionite extract; EPY = pyrophosphate extract; ESC = NaCl extract.

Mean values for soil pH, % organic carbon and cation exchange capacity for sites associated with yellow birch foliage sampling, by OMNR Districts.

OMNR DISTRICT	SOIL HORIZON:	pH (CaCl2)			pH (water)			% Organic Carbon			Cation Exchange Capacity (meq/100g)		
		A	B	C	A	B	C	A	B	C	A	B	C
ALGONQUIN		3.9	4.3	4.4	4.4	4.7	4.8	4.6	4.7	2.8	4.5	2.3	1.4
AYLMER		5.2	5.3	6.9	5.7	6.1	7.4	3.8	0.4	0.7	9.0	1.8	5.3
BANCROFT		4.5	4.4		5.0	4.9		7.7	3.5		7.6	2.3	
BLIND RIVER		3.4	4.2		3.9	4.6		4.1	5.0		5.0	3.4	
BRACEBRIDGE		3.5	4.3	4.6	4.0	4.6	5.1	6.3	4.3	1.6	4.8	3.1	1.1
CORNWALL		4.2	4.3	4.7	4.8	4.8	5.3	6.7	2.7	0.7	7.3	3.3	2.8
HURONIA		5.7	5.5	5.0	6.1	6.1	5.7	4.2	1.7	0.9	13.3	5.8	0.8
MAPLE		6.2	6.3		6.5	6.7		7.8	1.7		29.5	10.8	
MINDEN		4.1	4.3	4.3	4.6	4.7	4.7	3.6	5.2	5.3	2.8	2.7	2.9
NAPANEE		6.2	6.2	6.2	6.6	6.7	6.8	5.4	1.1	1.0	16.1	14.0	14.0
NORTH BAY		3.5	4.2	4.4	3.8	4.5	4.8	3.9	4.8	1.8	2.9	2.7	1.0
PARRY SOUND		4.0	4.3	4.5	4.6	4.8	5.2	6.6	4.9	2.1	3.4	2.6	0.8
SAULT STE MARIE		3.6	4.2	4.4	4.0	4.6	4.7	3.5	5.3	3.7	4.2	2.7	1.5
SIMCOE		5.9	5.6	7.3	6.4	6.4	7.8	4.5	1.1	0.9	9.0	3.0	8.4
SUDBURY		3.7	4.0	4.2	4.2	4.5	5.3	2.7	1.4	0.2	6.6	4.8	4.1
TWEED		4.2	4.3		4.5	4.7		3.3	2.2		2.7	1.8	
WAWA		3.3	4.2		3.7	4.7		1.6	5.9		3.8	5.4	

Mean values for calcium and magnesium levels in the soil and in yellow birch foliage samples, by OMNR Administrative Districts.

OMNR DISTRICT	SOIL Ca (meq/100g) A	SOIL Ca (meq/100g) B	SOIL Ca (meq/100g) C	FOLIAGE Ca (%)	SOIL Mg (meq/100g) A	SOIL Mg (meq/100g) B	SOIL Mg (meq/100g) C	FOLIAGE Mg (%)
ALGONQUIN	3.0	0.5	0.2	1.333	0.43	0.08	0.05	0.255
AYLMER	7.9	1.4	4.7	1.600	1.06	0.31	0.43	0.290
BANCROFT	6.9	0.9		1.640	0.03	0.16		0.326
BLIND RIVER	1.9	0.9		1.340	0.36	0.13		0.281
BRACEBRIDGE	2.7	0.7	0.4	1.230	0.47	0.09	0.05	0.271
CORNWALL	5.7	1.3	2.0	1.400	0.92	0.19	0.52	0.307
HURONIA	11.8	5.2	0.5	1.800	1.24	0.47	0.05	0.325
MAPLE	26.8	10.1		2.660	2.31	0.61		0.328
MINDEN	1.4	1.1	1.0	1.193	0.21	0.16	0.16	0.295
NAPANEE	12.9	10.2	10.1	1.860	2.83	3.53	3.63	0.410
NORTH BAY	0.9	0.5	0.2	1.196	0.24	0.09	0.03	0.249
PARRY SOUND	2.0	1.0	0.4	1.332	0.28	0.10	0.05	0.299
SAULT STE MARIE	1.4	0.5	0.4	1.073	0.26	0.05	0.03	0.241
SIMCOE	8.0	2.7	7.9	1.540	0.89	0.29	0.47	0.282
SUDBURY	1.9	0.7	1.6	1.220	0.78	0.25	1.99	0.316
TWEED	0.6	0.4		1.420	0.11	0.06		0.328
WAWA	0.2	0.2		0.994	0.09	0.06		0.174

Mean values for nitrogen and potassium levels in the soil and in yellow birch foliage samples, and for phosphorus levels in yellow birch foliage (soil levels not available) by OMNR Administrative Districts.

OMNR DISTRICT	SOIL N (%)			FOLIAGE N (%)	SOIL K (%)			FOLIAGE K (%)	FOLIAGE P (%)
SOIL HORIZON:	A	B	C		A	B	C		
ALGONQUIN	3.0	3.1	1.9	2.58	0.15	0.04	0.03	1.17	0.18
AYLMER	3.9	0.3	0.7	2.85	0.09	0.04	0.08	1.07	0.18
BANCROFT	8.4	2.6		2.27	0.02	0.07		1.40	0.16
BLIND RIVER	2.2	2.8		2.37	0.14	0.08		0.96	0.14
BRACEBRIDGE	3.5	2.5	1.5	2.68	0.15	0.05	0.02	1.10	0.17
CORNWALL	4.4	1.8	0.7	2.61	0.21	0.07	0.05	1.43	0.21
HURONIA	3.4	1.3	0.6	2.52	0.10	0.05	0.01	1.00	0.16
MAPLE	6.5	1.6		2.00	0.27	0.06		0.89	0.25
MINDEN	2.4	2.0	3.4	2.29	0.05	0.04	0.07	0.94	0.22
NAPANEE	4.3	1.0	0.8	2.28	0.43	0.28	0.22	1.17	0.20
NORTH BAY	2.8	2.8	1.0	2.69	0.11	0.05	0.03	1.12	0.21
PARRY SOUND	4.2	2.5	1.2	2.63	0.11	0.03	0.02	1.27	0.16
SAULT STE MARIE	2.3	2.8	2.0	2.69	0.08	0.04	0.02	1.11	0.13
SIMCOE	2.8	0.5	0.6	2.40	0.10	0.04	0.07	1.09	0.17
SUDBURY	2.2	1.0	0.3	2.38	0.20	0.09	0.06	1.11	0.21
TWEED	2.2	1.4		2.62	0.08	0.09		1.34	0.18
WAWA	1.3	3.2		2.87	0.09	0.06		1.30	0.14

Mean values for nickel and lead levels in the soil and in yellow birch foliage samples, and for cadmium levels in yellow birch foliage (soil levels not available) by OMNR Administrative Districts.

OMNR DISTRICT	SOIL Ni (ppm) A	SOIL Ni (ppm) B	SOIL Ni (ppm) C	FOLIAGE Ni (ppm)	SOIL Pb (ppm) A	SOIL Pb (ppm) B	SOIL Pb (ppm) C	FOLIAGE Pb (ppm)	FOLIAGE Cd (ppm)
ALGONQUIN	5.1	9.4	9.5	3.2	19.7	9.6	8.8	2.61	3.3
AYLMER	8.8	7.2	17.0	1.1	35.0	12.0	19.0	2.42	1.8
BANCROFT	11.0	11.0		3.5	37.0	13.0		2.40	2.6
BLIND RIVER	4.5	12.5		2.1	19.0	19.3		1.66	3.1
BRACEBRIDGE	5.9	11.3	11.0	2.8	18.3	16.1	4.0	2.91	3.1
CORNWALL	8.9	16.7	17.3	1.8	29.0	12.0	10.5	3.21	2.1
HURONIA	12.6	15.1	6.8	1.3	28.8	20.4	3.8	1.40	1.5
MAPLE	8.3	7.1		1.0	39.0	10.0		2.94	1.0
MINDEN	11.0	13.5	17.0	2.8	16.4	16.4	24.0	2.65	3.1
NAPANEE	27.0	49.0	44.0	1.1	31.0	21.0	20.0	1.94	1.3
NORTH BAY	7.2	12.5	13.4	4.8	25.7	20.5	10.4	4.50	2.9
PARRY SOUND	10.5	12.7	10.6	3.2	26.7	19.8	12.0	2.74	2.7
SAULT STE MARIE	5.9	14.9	24.0	2.0	23.9	16.9	17.0	1.48	2.3
SIMCOE	16.0	14.5	28.5	1.2	78.5	28.5	37.5	1.70	2.0
SUDBURY	19.0	22.0	15.0	7.7	17.0	8.1	3.8	2.52	3.7
TWEED	16.0	14.0		2.0	26.0	8.4		2.46	1.7
WAWA	5.2	14.0		1.7	9.9	18.5		1.56	3.5